Fermi National Accelerator Laboratory

FERMILAB-Conf-76/61-THY
July 1976

Summary Talk--Status of Accelerator Neutrino Physics

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Given at Aachen Neutrino Conference, June 11, 1976; to appear in the Proceedings.

I. THEORETICAL BACKGROUND

Throughout the Conference, there have been excellent theoretical talks which covered a wide range of theoretical questions pertinent to neutrino physics. The proceeding speaker, Professor Abdus Salam, spoke most eloquently of the general problems confronting our basic understanding of the subatomic world. While I might differ with him on the question of color confinement only in detail, I am very comfortable with his general philosophy. I am particularly impressed by his statement about the criterion of a successful science; it is the simplicity and elegance of principles one abstracts, and not the complexity of morphology and classifications with which one has to deal. To paraphrase, we should not be afraid of the proliferation of quarks and "glues" in our "zoo", but instead we must strive to understand the basic principles which govern the nature of their structures and interactions.

There is no sense in my trying to match Professor Salam's profundity and eloquence. Instead, as a theorist who lives in the milieu of experimentalists I shall address theoretical questions that are immediately relevant to today's accelerator neutrino physics. The frame of reference I shall dwell in is quantum chromodynamics, in which quarks are assumed to carry both flavors and colors, and confining forces among quarks are transmitted by color gluons. The physical hadrons are color-neutral. Quarks presumably cannot be isolated at least at the present accelerator energies. For most phenomenological considerations, whether confinement is permanent or temporary does not really matter, but I insist that quarks behave as if they were free at short distances, and color symmetry is exact. Inasmuch as a quark cannot exist in an isolated state, what one means by a quark mass is a matter of definition. One definition might be more superior than others in a given context. A particular definition of a quark mass, and its determination was discussed at this Conference (Krenz-Aachen).

A. Quark-Parton Model

Let me begin with the basics. When a nucleon is viewed in a frame of reference in which it moves with the velocity of light, it behaves as a collection of co-moving quasi-free quark partons at any instant, according to the parton model. Let the momentum of the nucleon be P, and the fraction of the longitudinal momentum k carried by a particular parton be x. That is,

$$k = xP , \qquad 0 \leq x \leq 1 \tag{1}$$

It is best to view the interaction of a neutrino (or an antineutrino) and the nucleon in the center-of-mass frame of the neutrino (antineutrino) and the colliding parton.

Let us recall that in the conventional V-A theory, only left-handed neutrinos and partons (L), and right-handed antineutrinos and antipartons (R) participate in weak interactions. It is convenient to define a variable y,

$$y = \frac{1 - \cos\theta^{*}}{2} \tag{2}$$

where θ^* is the scattering angle in this center-of-mass frame. For a collision of the like-helicity particles, the cross-section is given by

$$\frac{d\sigma}{dy} = \frac{G_F^2 s}{2\pi} , \quad s = (k + \ell)^2 \tag{3}$$

ℓ being the momentum of the incoming lepton.

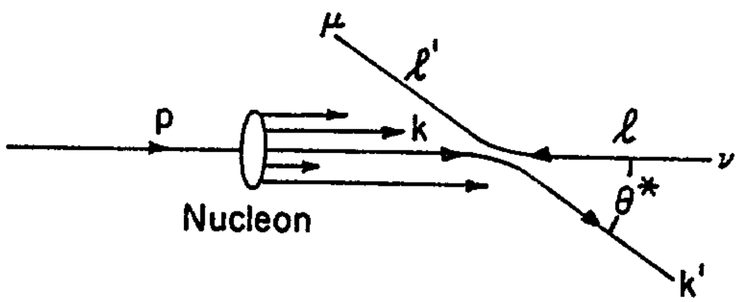


Fig. 1. Kinematics of neutrino-nucleon collision in the parton model.

The above formula applies to neutrino-parton, and antineutrino-antiparton collisions.

For a collision of the opposite-helicity particles, backward scattering ($\theta^* = \pi$) is forbidden by the conservation of angular momentum. The cross-section in this case is given by

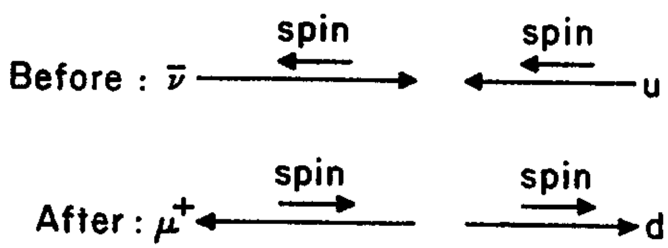


Fig. 2. For a collision of unlike-helicity particles, backward scattering is forbidden by the angular momentum conservation along the direction of motion.

$$\frac{d\sigma}{dy} = \frac{G_F^{\,2} s}{2\pi} \; \frac{1 + \cos\theta^*}{2} = \frac{G_F^{\,2} s}{2\pi} \; (1 - y)^2 \tag{4}$$

This formula applies to antineutrino-parton and neutrino-antiparton collisions.

Let f(x) be the parton density at x, and $\bar{f}(x)$ the antiparton density at x. The neutrino-nucleon and antineutrino-nucleon cross-sections are given by

$$\frac{d^2\sigma^{\nu N}}{dx\,dy} = \frac{G_F P\cdot\ell}{\pi} \; x\left[f(x) + \bar{f}(x)(1 - y)^2\right]$$

$$\frac{d^2\sigma^{\bar{\nu} N}}{dx\,dy} = \frac{G_F P\cdot\ell}{\pi} \; x\left[f(x)(1 - y)^2 + \bar{f}(x)\right] \tag{5}$$

These formulas apply to inclusive measurements, that is, to those experiments in which one does not restrict the hadronic final states.

The quantities x and y are directly measurable in the laboratory frame, where $P \cdot \ell = m_N E_\nu$, and $q = \ell' - \ell$.

	neutrino-parton C.M. frame	Laboratory frame
x	$k_\pi / \lvert\vec{P}\rvert$	$-q^2/2m_N(E_\nu - E_\mu)$
y	$\frac{1 - \cos\theta^*}{2}$	$(E_\nu - E_\mu)/E_\nu$

Denoting xf(x) and $x\bar{f}(x)$ by F(x) and $\bar{F}(x)$, we can write

$$\frac{d^2\sigma^{\stackrel{\nu}{\bar{\nu}}N}}{dx\,dy} = \frac{G_F m_N E_\nu}{\pi}\left\{F(x)\begin{bmatrix}1\\(1-y)^2\end{bmatrix} + \bar{F}(x)\begin{bmatrix}(1-y)^2\\1\end{bmatrix}\right\} \qquad (6)$$

Thus, if there are no new phenomena, inclusive measurements which involve only E_μ, $E_h \equiv E_\nu - E_\mu$, and $-q^2 = 2E_\nu E_\mu(1 - \cos\theta)$ will map out the profile of the parton distribution functions $F(x)$ and $\bar{F}(x)$.

B. Breakdown of Scaling

The fact that the inclusive cross-sections (6) can be written in a scaled form has to do with the assumptions that partons are light, and that they act as if they are free. The latter assumption is all right as long as $Q^2 = -q^2$ is moderate. However, if Q^2 is large, the partons move in a rapidly varying external field generated by the lepton, and loose their momenta by gluon-bremsstrahlung. This has the effect that the parton distribution is a function of both x and Q^2, $F = F(x, Q^2)$, and as Q^2 increases, partons tend to concentrate towards lower values of x.

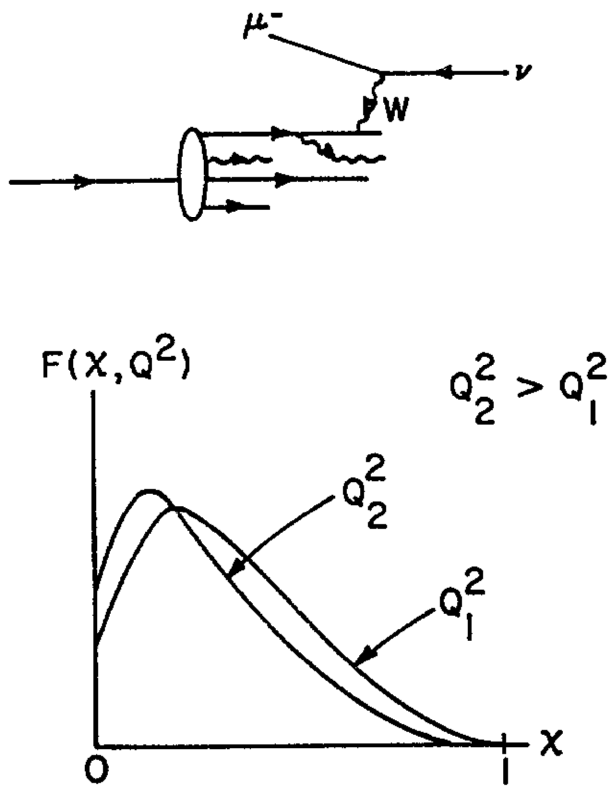


Fig. 3. As Q^2 increases, partons loose momenta by gluon-bremsstrahlung. The parton distribution shifts toward lower x as Q^2 increases.

Another important effect as Q^2 increases is that the virtual W bosons interact with gluons, and pairs of parton-antipartons are produced more and more. Thus, as Q^2 increases, the antiparton distribution increases everywhere in x. [Of course this process increases

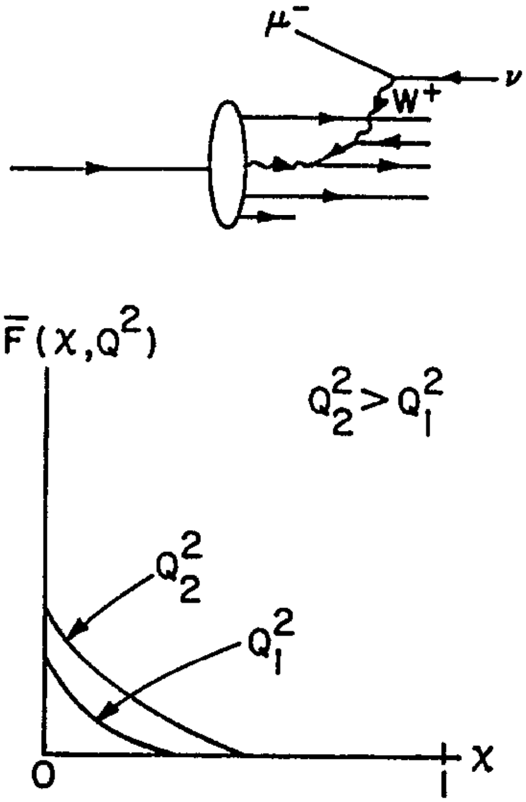


Fig. 4. Pair production by gluon-W boson collision becomes more copious as Q^2 increases; antiparton content of a nucleon increases thereby.

the parton content near x = 0 as well, but this increase was taken into account in the plot of F(x, Q^2) in Figure (3) above].

The Q^2 dependence of the structure functions F and $\bar{F}$ discussed above is common to all reasonable field theories, and represents the quintessential quantum mechanical effect that the very act of observation interferes with reality--in this case, parton, antiparton distributions.

In the so-called asymptotic free field theories such as QCD, the Q^2 dependence of moments of the structure functions is computable, and is mild in the sense that

$$\lim_{Q^2 \to \infty} \int_0^1 dx\, x^n F(x, Q^2) \sim (\ln Q^2)^{-\gamma_n} \tag{7}$$

where γ_n is a computable number. I have plotted in Figure 5 an expected change in the structure function $F_2^{\gamma N}$ in electroproduction as Q^2 varies from 1 to 25 $(\text{GeV})^2$. In this plot, I have used a somewhat larger gluon-quark coupling constant than warranted by the best fit to the extant Fermilab deep inelastic muon scattering data.

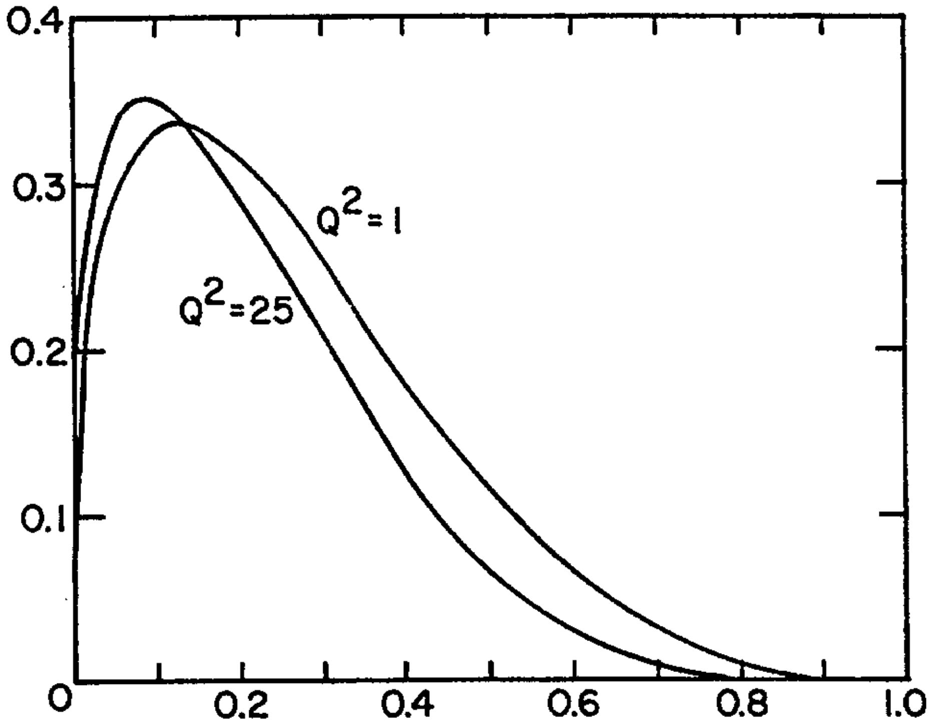


Fig. 5. The plot of $F_2^{\gamma N}(x, Q^2) = \frac{5}{18} F(x, Q^2) + \frac{5}{18}\bar{F}(x, Q^2)$ for $Q^2 = 1$ and $25(\text{GeV})^2$. $\alpha_s(\mu^2 = 1\ \text{GeV}^2) = 0.5$ is used in this plot.

C. Gauge Theory of Weak and Electromagnetic Interactions

In the currently popular $SU(2) \times U(1)$ gauge theory, there are two independent coupling constants, g associated with weak isospin $\vec{T}_W$, and g' associated with weak hypercharge Y_W. The electric charge operator Q is $(T_W)_3 + Y_W/2$.

The coupling of the massive neutral vector boson Z_μ to particles is given by

$$\mathscr{L}_Z = \sqrt{g^2 + g'^2}\; Z_\mu \left(j_3^\mu - \sin^2 \theta_W\, j_{em}^\mu \right) \tag{8}$$

where $\sin \theta_W = g'/(g^2 + g'^2)^{\frac{1}{2}}$. (9)

In the minimal scheme of Weinberg and Salam, where we ignore the strange quark (or put the Cabibbo angle $\theta_C = 0$), we place u_R and d_R as singlets and

$$\begin{pmatrix} u \\ d \end{pmatrix}_L$$

as a doublet. The third component of weak isospin current is given by

$$j_\mu^{\,3} = (\bar{u}, \bar{d})_L \frac{\tau_3}{2} \begin{pmatrix} u \\ d \end{pmatrix}_L = \tfrac{1}{2}\, \bar{u}_L \gamma_\mu u_L - \tfrac{1}{2}\, \bar{d}_L \gamma_\mu d_L \ . \tag{10}$$

Note, however, that the neutral current need not be parity violating. As a random example, consider a scheme in which there are three doublets

$$\begin{pmatrix} u \\ d \end{pmatrix}_L , \begin{pmatrix} u \\ b \end{pmatrix}_R , \begin{pmatrix} t \\ d \end{pmatrix}_R$$

where t and b are massive quarks not relevant to low energy spectroscopy. In this case

$$j_\mu^{\ 3} = \frac{1}{2}\bar{u}\gamma_\mu\left(\frac{1-\gamma_5}{2}\right)u - \frac{1}{2}\bar{d}\gamma_\mu\left(\frac{1-\gamma_5}{2}\right)d$$

$$+ \frac{1}{2}\bar{u}\gamma_\mu\left(\frac{1+\gamma_5}{2}\right)u - \frac{1}{2}\bar{d}\gamma_\mu\left(\frac{1+\gamma_5}{2}\right)d + \text{contributions from t and b}$$

$$= \frac{1}{2}\bar{u}\gamma_\mu u - \frac{1}{2}\bar{d}\gamma_\mu d + \ldots$$

which is parity-conserving as far as light quarks are concerned. The moral of this silly exercise is that, <u>in the framework of a gauge theory</u>, the existence of heavy quarks affects the structure of neutral current even below the heavy particle production threshold. Here lies the importance of the studies of neutral current effects such as $\nu p \to \nu p$ and inclusive process $\nu p \to \nu X$.

The strength of charged current × charged current interactions is known as the Fermi constant, and it is given by

$$\left[\frac{G_F}{\sqrt{2}}\right]_{CC} = \frac{g^2}{8m_W^{\ 2}} .$$

The strength of neutral current × neutral current interactions is

$$\left[\frac{G_F}{\sqrt{2}}\right]_{NC} = \frac{g^2+g'^2}{8m_W^{\ 2}} = \chi^2\left[\frac{G_F}{\sqrt{2}}\right]_{CC} .$$

In principle, χ^2 is an arbitrary parameter. In the doublet Higgs scheme used by Weinberg and Salam,

$$\frac{m_W^2}{m_Z^2} = \frac{g^2}{g^2 + g'^2}$$

so that $\chi^2 = 1$. The experimental evidence to be summarized seems to support this hypothesis, i.e., $\chi^2 \approx 1$.

D. More Quarks--New Physics

D1. Charm

It is by now an old story that the absence of $\Delta S \neq 0$ neutral current effects led to hypothesizing of the existence of a fourth quark carrying charm quantum number by Bjorken and Glashow, and by Glashow, Iliopoulos and Maiani in the context of a gauge theory. In the minimal scheme, one postulates two weak-isospin doublets

$$\begin{pmatrix} u \cos\theta_C - c \sin\theta_C \\ d \end{pmatrix}_L , \qquad \begin{pmatrix} u \sin\theta_C + c \cos\theta_C \\ s \end{pmatrix}_L .$$

It is widely accepted that the psion family of new particles are composites of $c\bar{c}$.

It is quite likely that we have seen some of the low-lying charmed particles already (see below). Some of them are

$$D^+(c\bar{d}) \longrightarrow \bar{K}^0 \ell^+ \nu , \; \bar{K}^0 \phi \ell^+ \nu \tag{11}$$

$$K^-\pi^+\pi^+ \quad , \tag{12}$$

$$D^0(c\bar{u}) \quad \rightarrow K^- \ell^+ \nu, \tag{13}$$

$$K^-\pi^+, \; K^-\pi^+\pi^+\pi^-, \tag{14}$$

$$C_1^{*++}(cuu) \quad \rightarrow C_0^+\pi^+ \rightarrow \Lambda\pi^+\pi^+\pi^+\pi^- \tag{15}$$

$$C_0^+(cud) \quad \rightarrow \Lambda\pi^+\pi^+\pi^- \tag{16}$$

$$\Lambda \ell^+ \nu \tag{17}$$

D2. Vectorlike Model

The vectorlike model with equal numbers of right-handed and left-handed doublets, which was much discussed until recently, may rest in peace, it appears now. In this version of a vectorlike theory, the electronic and hadronic neutral currents are parity conserving. There seem now to be sufficient pieces of evidence to exclude this possibility both from neutrino physics and atomic physics.

D3. Still More Quarks?

In conjunction with the possible anomaly in the antineutrino y distribution and the increase in $\sigma^{\bar{\nu}}/\sigma^{\nu}$, the following model appeals to some people:

$$\begin{pmatrix} u_c \\ d \end{pmatrix}_L \quad , \begin{pmatrix} c_c \\ s \end{pmatrix}_L \; ; \begin{pmatrix} u \\ b \end{pmatrix}_R \quad . \tag{18}$$

This is the model discussed by Achiman, Koller and Walsh[1]; the models of Fayet[2], Barnett[3], and those of Gürsey, Sikivie and Ramond[4] motivated by considerations based on exceptional groups, have much in common with the AKW model in this regard. In this model, in addition to the usual process

$$\underset{R}{\bar{\nu}} + \underset{L}{u} \rightarrow \underset{R}{\mu^+} + \underset{L}{d}$$

which produces a $(1 - y)^2$ distribution, and therefore contributes to the total cross-section only 1/3 of the ν total cross-section, there is a new process

$$\underset{R}{\bar{\nu}} + \underset{R}{u} \rightarrow \underset{R}{\mu^+} + \underset{R}{b} \tag{19}$$

above the b-quark threshold, which produces a flat y distribution. When threshold effects are duly taken into account, this class of models can explain the so-called high y-anomaly and the increase in $\sigma^{\bar{\nu}}/\sigma^{\nu}$ adequately.

If one takes the AKW model seriously, it is very tempting to assign leptons to three doublets:

$$\begin{pmatrix} \nu_e \\ e \end{pmatrix}_L , \quad \begin{pmatrix} \nu_\mu \\ \mu \end{pmatrix}_L ; \begin{pmatrix} \nu_U \\ U^- \end{pmatrix}_R$$

where U^- is the heavy lepton reported by Marty Perl.

In a recent paper Poggio, Quinn and Weinberg[5] proposed a smearing method to compare the experimentally measured R

$$R = \sigma(e^+e^- \to \text{"hadrons"}) / \frac{4\pi}{3} \frac{\alpha^2}{s}$$

and the theoretical prediction based on QCD. Their best fit, shown in Figure 6, was obtained with

No. of quarks	m_b	charge	No. of heavy leptons	m_U
5	2.5 GeV	1/3	1	1.7 GeV.

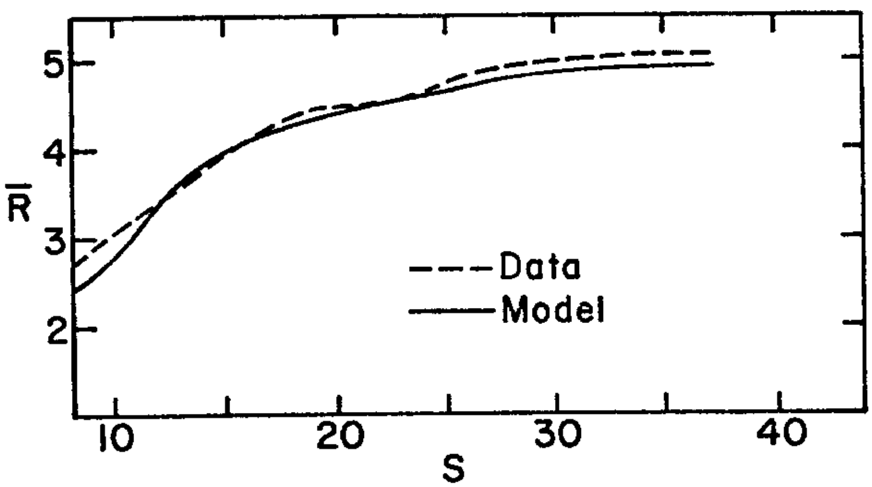


Fig. 6. smeared R. The full line is the smeared experimental data; the dotted line the smeared theoretical prediction based on the model discussed in the text. (From E. Poggio, H. Quinn and S. Weinberg).

I do not mean to oversell the five quark model. Rather, I am presenting it to you as a curiosity deserving your attention. The model as written down in (18) has several defects; for one, in this scheme, the GIM mechanism is not "natural" in the technical sense; for another, as Cecilia Jarlskog stressed at this Conference, this model predicts the sign for parity violation effects in atomic physics to be opposite to the prediction of the minimal model. If the present, tentative findings of the ongoing atomic physics experiments on parity violating effects should prevail, then these particular five and six quark models would have to be rejected.

D4. In Parting

Theorists like to invent models, and understandably some of our colleagues are disturbed and bewildered by the profusion of models of short lifetimes. In defense of model builders, I must repeat a sage uttering of my colleague, Chris Quigg: "More exciting is our certain knowledge that nature's possibilities are not limited by our imagination."

II. EXPERIMENTAL RESULTS

Since the discoveries of the dimuon events and of the J/ψ particle, there have been a large number of experimental findings which are indicative of the onset of new kinds of phenomena. Most of these were reported at this Conference; let me review them in a random order.

A. Observation of a $K^{\pm}\pi^{\mp}\pi^{+}\pi^{-}$, $K^{\pm}\pi^{\mp}$ resonance at SPEAR as reported here by Vera Lüth. The mass of this resonance is

$$M = 1865 \pm 15 \text{ MeV}.$$

The width is consistent with zero. The experimental evidence is <u>very convincing</u>. It is very suggestive of the D^0, $\overline{D}^0$ meson decays as indicated in Eq. (14). However, in order to know that this object carries charm, it is necessary to detect its decays into $\pi^+\pi^-$, $\pi^+\pi^-\pi^+\pi^-$ which should occur at Cabibbo-suppressed rates. To take advantage of a favorable signal/noise ratio, one might also search the same resonance in the $K\bar{K}$ channel.

As Alvaro De Rujula pointed out, the recoil mass distribution suggests the production mechanisms

$$\begin{aligned} e^+ + e^- \rightarrow \gamma \rightarrow\; & D^0 + \overline{D^{0*}} \\ & \quad \hookrightarrow K^-\pi^+ \\ \rightarrow\; & D^- + D^{+*} \\ & \quad \hookrightarrow D^0 + \pi^+ \\ & \qquad\quad \hookrightarrow K^-\pi^+ . \end{aligned}$$

B. Interpretation of $e^{\pm}\mu^{\mp}$ events at SPEAR as production and decays of heavy leptons (M. Perl): $e^{+} + e^{-} \rightarrow \gamma \rightarrow U^{+} + U^{-}$. This interpretation, based on various tests, appears convincing, and yields a mass

$$M(U^{\pm}) \approx 1.7 \text{ GeV}.$$

C. Psion spectroscopy was discussed by Lüth and Schmitz. The three ^{3}P states at 3.4, 3.5 and 3.55 GeV seem well-established. There are some worries though. The objects at 2.8 GeV (observed at DORIS) and at 3.45 GeV (observed at SPEAR) are enigmas. Are they the ^{1}S counterparts of ψ and ψ'? Why have their hadronic decays not been seen? In any case, DESY reports

$$BR(\psi' \rightarrow 2.8 + \gamma) \cdot BR(2.8 \rightarrow \gamma + \gamma) \leq 3.7 \times 10^{-4},$$

$$BR(\psi \rightarrow 2.8 + \gamma) \cdot BR(2.8 \rightarrow \gamma + \gamma) \simeq 1.6 \times 10^{-4}.$$

D. The DASP collaboration at DORIS has observed events with an electron associated with several charged tracks (and γ's). The cross-section is quoted to be

$$\sigma(e^{+} + e^{-} \rightarrow e^{\pm} + \geq 3 \text{ prongs}) \simeq 1 \text{ to several nb},$$

at $E_{CM} = 3.95$ to 4.2 GeV. These events ($20 \sim 30$) may come from semi-leptonic decays of charmed particles.

E. Staude gave a comprehensive discussion on the high $p_{\perp}$ lepton production phenomena in pp collisions. Recently Bourquin and J.-M.

Gaillard (the latter is not to be confused with our Madam Chairperson) have parametrized systematically various inclusive production cross-section in pp collisions, and have estimated the cross-section for high $p_\perp$ lepton production at $\theta^* = 90^o$. In Figure 7, I show their result for the ratio $(\ell/\pi)_{90^o}$

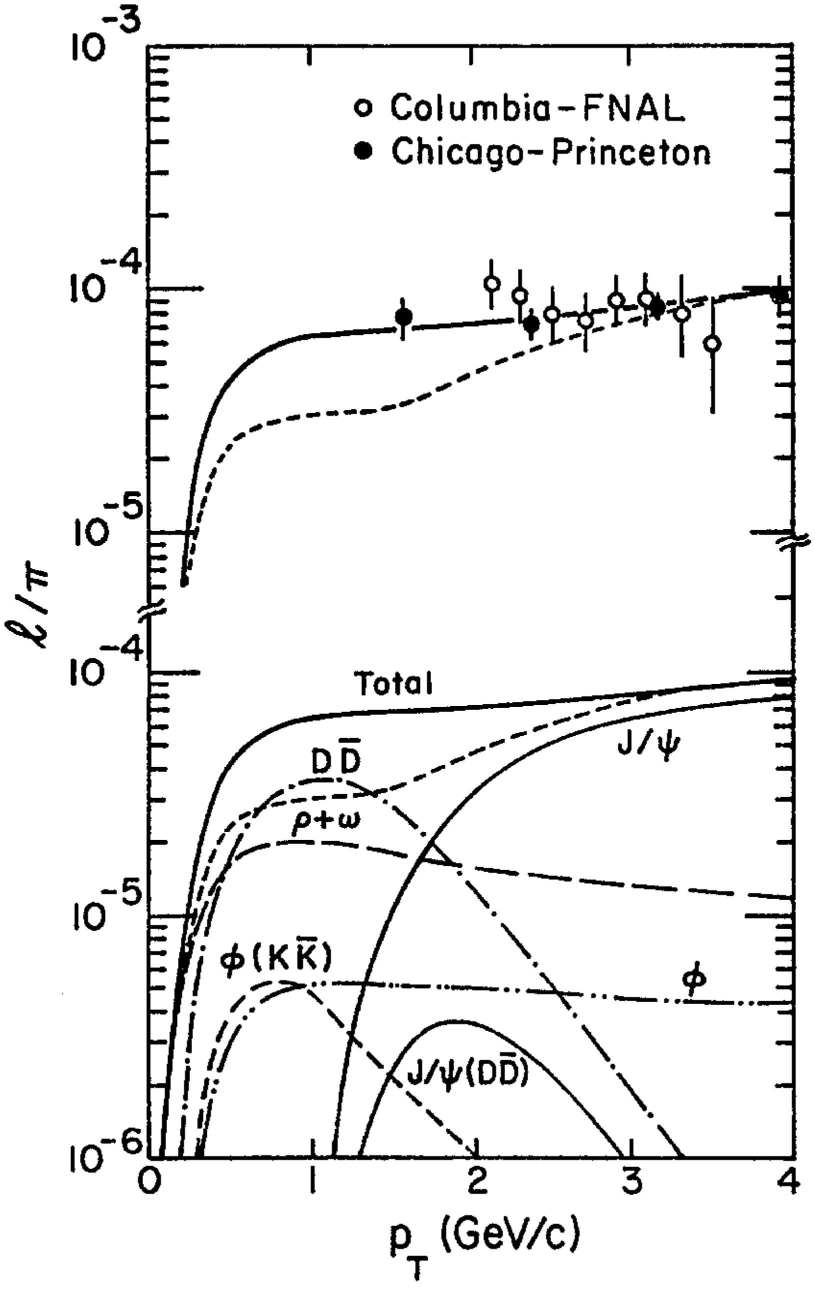


Fig. 7. The contributions of the various decays to the ℓ/π ratio as a function of p_T for $\sqrt{s} = 23$ GeV and $\theta = 90^o$. In the top part of the figure the data points are compared to the sum of the contributions with $D\bar{D}$ (full curve) and without (dashed curve). (From Bourquin and Gaillard).

vs. $p_\perp$. The conventional mechanisms such as

$$p + p \rightarrow V + X, \quad V \rightarrow \ell + \bar{\ell}$$

where $V = \rho^0$, ω, ϕ and J are not sufficient to explain the observed $(\ell/\pi)_{90^\circ}$ for $p_\perp \lesssim 2$ GeV. They propose to fill the gap by the associated production of charmed particle pairs ($D\bar{D}$) and the subsequent semileptonic decay $D(\bar{D}) \rightarrow \bar{K}(K) + \ell + \nu$ with a branching ratio of 15%. The parametrization of inclusive $D\bar{D}$ production cross-section is a priori determined by their experience with the cases of $p\bar{p}$ and $K\bar{K}$ productions, save for the overall normalization. They have adjusted the normalization so that $(\ell/\pi)_{90^\circ}$ is approximately 10^{-4} for $p_\perp \gtrsim 1$ GeV.

Thus, their parametrization gives a reasonable model for charmed pair production in pp collisions. This is, however, an upper bound on charmed pair production, since such plausible mechanisms as proposed by Drell and Yan, Bjorken and Weisberg, and Farrar and Frautschi, have not been included in their model. In any case, I shall use their estimates on charmed pair production as a guide in my discussion on searches for charmed particles in hadronic reactions. Figure 8 shows the total inclusive cross-section for

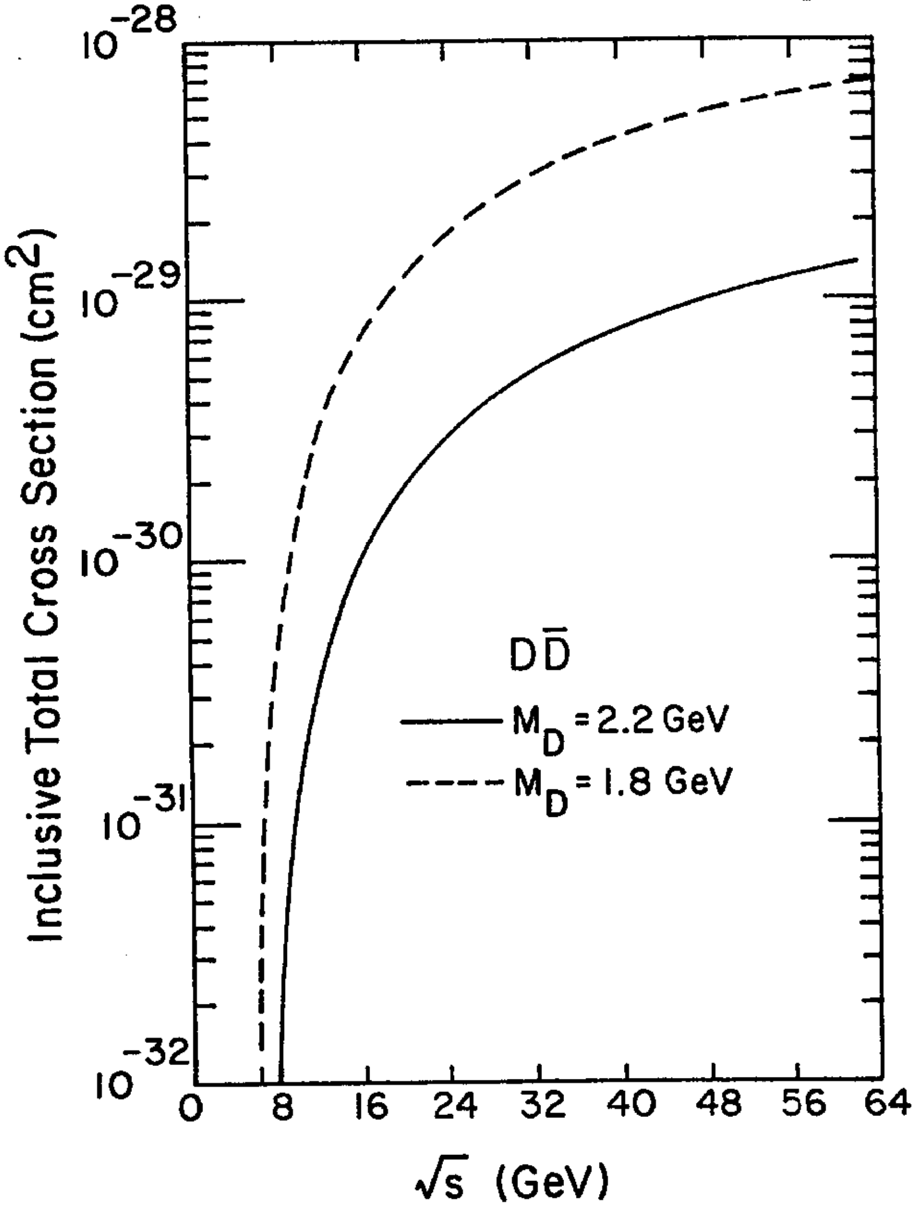


Fig. 8. The inclusive total cross-section for D(D) production in proton-nucleon collisions as a function of $\sqrt{s}$. (From Bourquin and Gaillard).

the process $p + p \to D + \bar{D} + X$, as estimated by them. Roughly it is of order 10^{-32} cm^2 = 10 nb at PS and AGS energies, 10^{-29} cm^2 = 10 μb at Fermilab energies, and 20 μb at ISR energies for M(D) = 1.86 GeV.

F. Searches for charmed particles in hadronic interactions have been reported by a number of speakers. All searches reported have been unsuccessful. I will present typical examples in a tabular form below:

Reaction	Reporter	Bourquin-Gaillard upper bound	Experimental upper bound
$p + Be \to \bar{D} + \ldots$ $\hookrightarrow \pi^- K^+$ $\sqrt{s} = 7.3$ GeV	U. Becker (MIT-BNL)	$10^{-34}\ cm^2$	10^{-33}
$\pi^- p \to D^0 \bar{D}^0 \pi^- p$: $D^0 \to K^- \pi^+$ $\bar{D}^0 \to K^+ \pi^-$ $\sqrt{s} = 6.2$ GeV	J. Bienlein (CERN Ω)	10^{-36}	8×10^{-33}
Emulsion Exposure $\sqrt{s} = 28.2$	Minguzzi-Ranzi (Padova)	10^{-29}	4×10^{-29}
$p\bar{p} \to V^0 n \pi^{\pm} + \ldots$ $\to V^0 e^{\pm} + \ldots$ $\sqrt{s} = 5.4$	(Tufts, MSU, Tohoku, Fermilab collaboration)	------	------

In compiling the table I have used $BR(D^0 \to K^- \pi^+) \sim 1\%$ as indicated by the recent SPEAR result.

Since charmed particles do exist, they must show up in proton accelerators sooner than later. As Mary K. Gaillard remarked, photoproduction of charmed pairs appears particularly promising. I recall a poem of

Percy Bysshe Shelley, which ends with "The trumpet of a prophecy! O, Wind,/ If Winter comes, can Spring be far behind?".

G. Dimuon events in ν and $\bar{\nu}$ interactions are firmly established at least for dimuons of opposite sign, and were reported here by Benvenuti (HPWF) and Khovalsky (Moscow-Serpukhov). The visible x and y distributions of these events are strongly indicative of the charm origin of these events, as explained to you by M. K. Gaillard. The observation of dimuon events at Serpukhov indicates that the threshold for this phenomenon may be much lower than hitherto thought, and may occur even at $E_\nu \lesssim 10$ GeV.

H. The observation of ν-induced $K^0\mu^-e^+$ events in the Fermilab 15' bubble chamber filled with light Ne mixture was reviewed by Jürgen von Krogh (Wisconsin-LBL-Hawaii-CERN collaboration). It was remarked by several theorists-speakers that the visible x and y distributions for these events are very similar to those of the dimuon events. It is very likely that these events are indicative of the process $\nu + N \rightarrow \mu^- + D^+ + X$ followed by $D^+ \rightarrow K^0 + e^+ + \nu_e + \ldots$. On the other hand, the number of K^0 and $\bar{K}^0$ per event is $N(K^0, \bar{K}^0) = 2. \pm 0.8$, an uncomfortably large number. It may be that this large number is subject to a statistical or scanning fluke, as Gaillard remarked; results from heavy Ne mixture exposures (Charles Baltay, BNL-Columbia collaboration) are eagerly awaited.

W. Lee (Columbia) and A. Lutz (Gargamelle) reported on μe events observed at BNL and in Gargamelle, respectively. While these events may be charm-related, they may arise from, for example, charmed baryon production and its subsequent semileptonic decays (17), rather than from charmed particle production in deep inelastic region. If this is the case, these events are more akin to the BNL event $\nu p \rightarrow \mu^- \Lambda \pi^+ \pi^+ \pi^+ \pi^-$ [see Eqs. (15) and (16)] as discussed by Bill Palmer here.

I am left with the impression that the question as to whether the reaction $\bar{\nu}N \rightarrow \mu^+ K_S(\Lambda) e^- + X$ takes place at a comparable rate has not been answered definitively.

I. The so-called high y anomaly in high energy $\bar{\nu}$ interaction, and the increase in the ratio $\sigma_{\bar{\nu}}/\sigma_{\nu}$ as observed by the HPWF collaboration were reviewed by Benvenuti. In the range 10 GeV $< E_{\bar{\nu}} <$ 30 GeV, the y distribution fits the expected $(1 - y)^2$ form very well; at higher energies, and especially above $E_{\bar{\nu}}$ = 70 GeV, the y-distribution deviates from the $(1 - y)^2$ form and becomes flatter. They have also examined the energy dependence of $\sigma_{\bar{\nu}}/\sigma_{\nu}$, by using ν and $\bar{\nu}$ events involving quasielastic scattering and resonance production for normalization (and also by using an extention of this method due to Sakurai), and found that the ratio increases from ~ 0.4 at low energies to ~ 0.6 above, say, 50 GeV. My understanding of the state of affairs is that their findings are consistent with the hypothesis that the increase in $\sigma_{\bar{\nu}}/\sigma_{\nu}$ is due to the high y anomaly, with perhaps no violation of charge symmetry relation at y = 0 even at high energies.

Barry Barish discussed the results of the CITF collaboration bearing on this question. The group does not yet have flux-normalized data, but analyzes its data using three different parametrizations of $d\sigma^{(\nu,\ \bar{\nu})}/dy$. Their conclusions support my understanding above of the HPWF results.

On the other hand, the situation becomes clouded when we look at the data from the two groups analyzing antineutrino events in the 15' bubble chamber. As Malcolm Derrick (ANL-CMU-Purdue collaboration; $\bar{\nu} + H_2$) and Frank Nezrick (Fermilab-Michigan-ITEP-IHEP collaboration; $\bar{\nu}$ + light Ne mixture) described, the bubble chamber data do not show clear indication of a high y anomaly. In fact the data Derrick presented, while statistically not as strong as the electronic counter data, are consistent with no anomaly at all at $\langle E_{\bar{\nu}} \rangle = 52$ GeV.

It is not my role to judge conflicting experimental findings. Rather, let me assume that there is an anomaly as described by the HPWF and CITF groups, and try to give a theoretical interpretation (the assessments given in this and the next paragraphs are based on a joint research with R. Shrock). Here again, there are conflicting views. Some theorists, especially Altarelli, Parisi and Petronzio of the Rome school, advocate the view that the breakdown of scaling predicted by QCD and charm production alone suffice to explain the high y anomaly and the increase in $\sigma_{\bar{\nu}}/\sigma_{\nu}$. Let me recall the formula (6) for $\bar{\nu}$:

$$\frac{d^2\sigma^{\bar{\nu}}}{dx\,dy} = \frac{G_F m_N E_{\bar{\nu}}}{\pi}\left[\bar{F}(x,\ Q^2) + F(x,\ Q^2)(1 - y)^2\right] \quad . \tag{19}$$

It must be noted that Q^2 is a function of x and y,

$$Q^2 = 2m_N E_{\bar{\nu}} xy \quad .$$

To obtain the y distribution, it is necessary to integrate (19) over x. Thus, we encounter integrals of the type

$$\int_0^1 dx\ F\big(x,\ Q^2(x,\ y)\big) \ , \tag{20}$$

for fixed y. This integral is not something that can be evaluated without more input. The asymptotically free QCD does tell us what the integral

$$\int_0^1 dx\ F(x,\ Q^2) \tag{21}$$

for fixed Q^2 is, and Altarelli, Parisi and Petronzio propose to evaluate Eq. (20) by the approximation

$$\int_0^1 dx\ F\big(x,\ Q^2(x,\ y)\big) \simeq \int_0^1 dx\ F\big(x,\ \bar{Q}^2(E_{\bar{\nu}})\big) \tag{22}$$

where $Q^2(E_{\bar{\nu}})$ is to be determined self-consistently, for example by,

$$\bar{Q}^2(E_{\bar{\nu}}) = 2m_N E_{\bar{\nu}} \langle xy \rangle_{E_{\bar{\nu}}} = \frac{\int dxdyxy\left[\bar{F}(x,\ \bar{Q}^2) + (1 - y)^2 F(x,\ \bar{Q}^2)\right]}{\int dxdy\left[\bar{F}(x,\ \bar{Q}^2) + (1 - y)^2 F(x,\ \bar{Q}^2)\right]}$$

While this method is ingenious, and worthy of further study, I am skeptical of the validity of the approximation schemes (22) and (23) (or something equivalent to it) in predicting the correct y distribution and the ratio $\sigma_{\bar{\nu}}/\sigma_{\nu}$. Furthermore the particular way in which they describe the onset of charmed particle production may be called into question. I have reproduced their plots for $\langle y \rangle^{\bar{\nu}}$ and $\sigma_{\bar{\nu}}/\sigma_{\nu}$ in Figure 9, in any event.

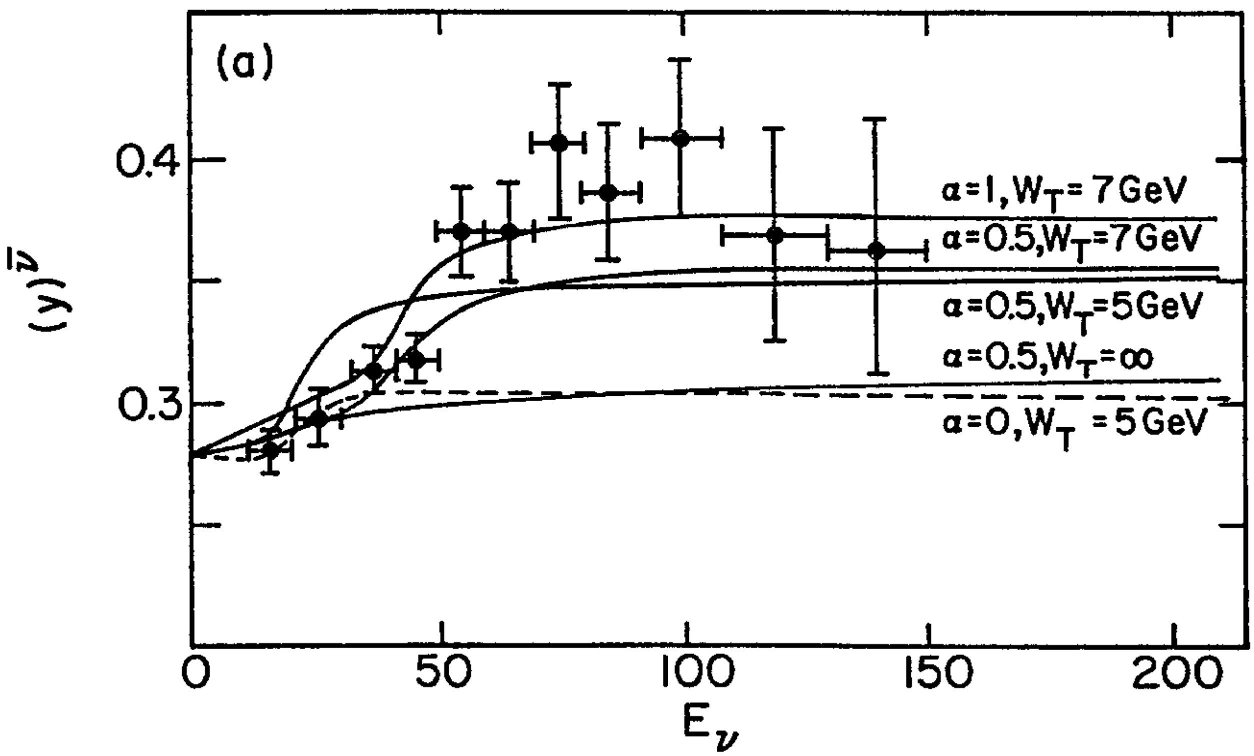
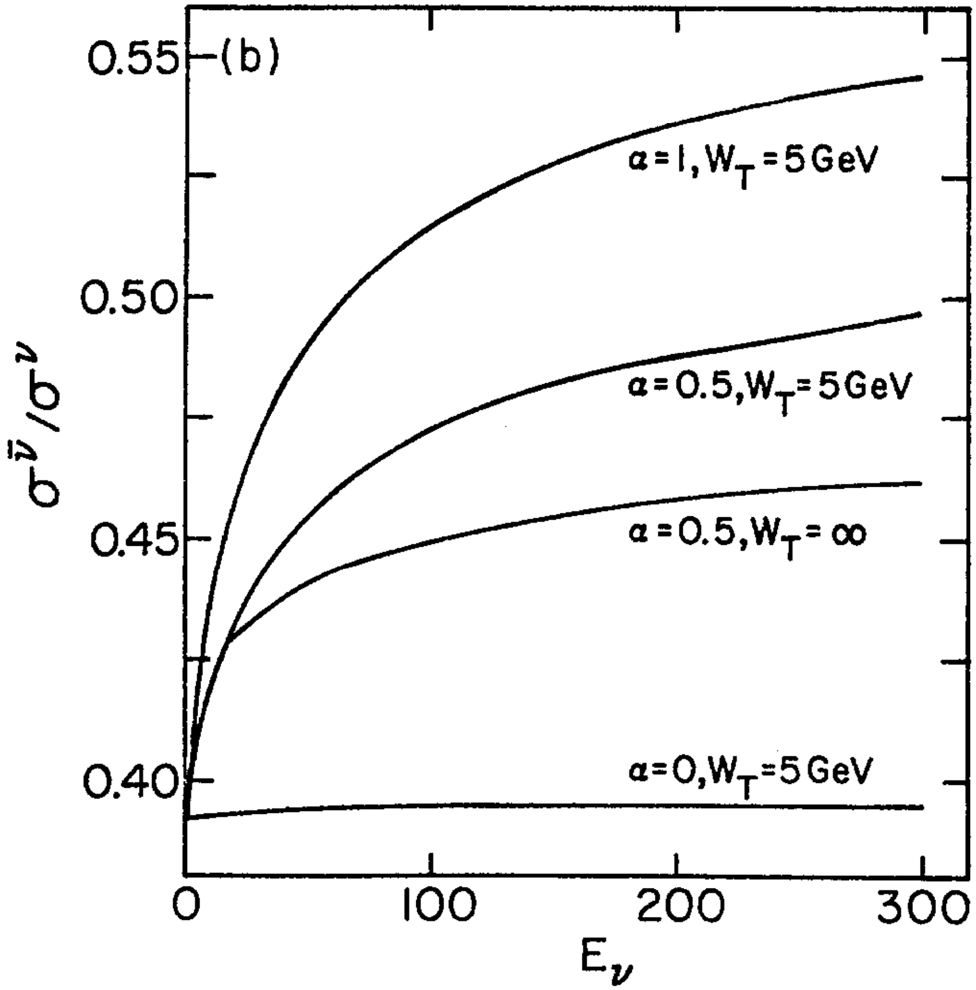


Fig. 9 (a). Average value of y for antineutrinos for different values of $\alpha \equiv \alpha_s(\mu^2)$ and W_T, the effective invariant mass for charm threshold. $\alpha = 0$ corresponds to Q^2 independent parton distributions. $W \to \infty$ corresponds to neglecting effects from charm production. Both effects seem to be needed to reproduce the data. $\alpha = 0.5$ is the value suggested in the text, while $\alpha = 1$ is reported for comparison. (From Altarelli, Parisi and Petronzio).



(b) The ratio $\sigma^{\bar{\nu}}/\sigma^{\nu}$ for different values of $\alpha \equiv \alpha_s(\mu^2)$ and W_T, the effective invariant mass for charm threshold. (From Altorelli, Parisi and Petronzio).

It is my opinion that, if the HPWF data are correct, their predictions with a reasonable range of parameters ($\gamma_s \equiv g_s^2/4\pi < 0.5$ at $\mu^2 = 1\ (\mathrm{GeV})^2$, μ^2 being the renormalization point, as indicated by deep inelastic muon scattering data, $W_T \approx 5 \sim 7$ GeV) underestimate the size of anomalies in $\langle y \rangle^{\bar{\nu}}$ and $\sigma_{\bar{\nu}}/\sigma_{\nu}$.

An alternative approach, which is particularly emphasized by Michael Barnett[3], and Carl Albright and Robert Shrock[7], involves production of new particles by the right-handed currents as explained in Eq. (19). For the heavy quark production, it is proper to use the scaling variable ξ

$$x \rightarrow \xi = x + \frac{m_b^2}{2m_N E_{\bar{\nu}} y}$$

where m_b is the mass of the heavy b = d' quark. Figure 10

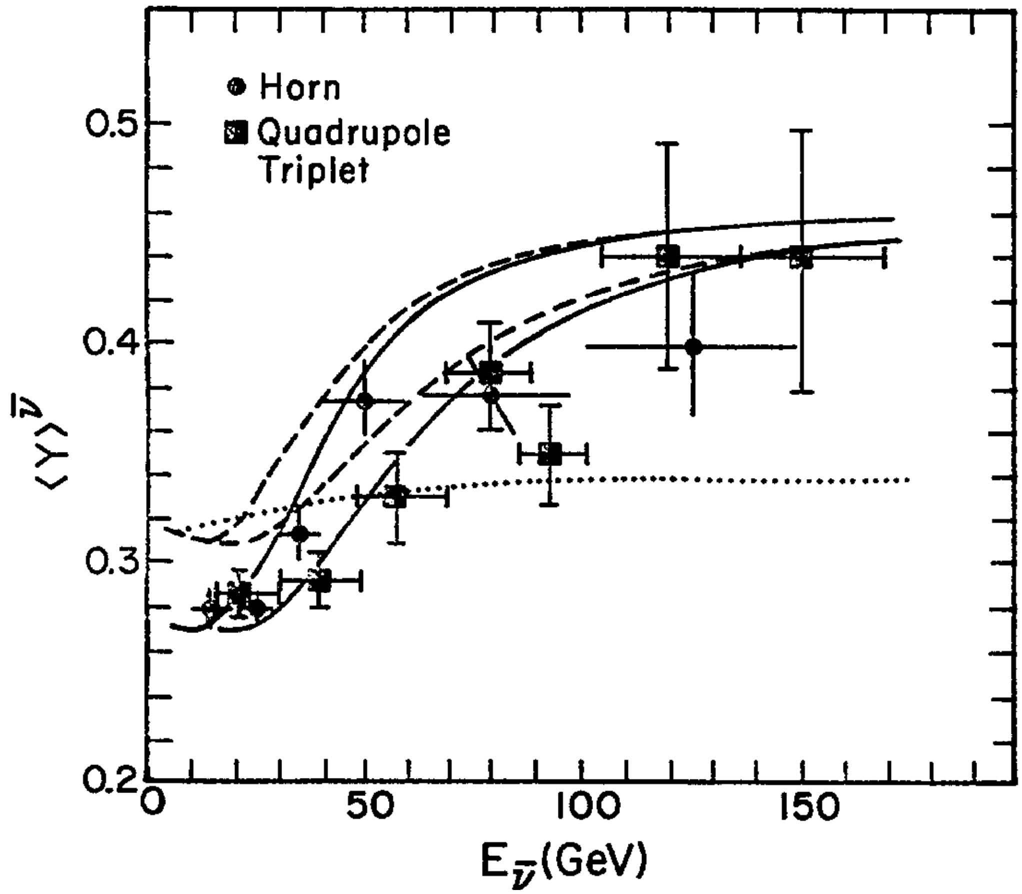


Fig. 10. The average value of y in the distributions for $\bar{\nu}N \rightarrow \mu^+ X$. Data is from HPWF. The curves are predictions for the standard model (dotted) and for model of Eq. (19) with 2% sea (soli and 11% sea (dashed), with m(d') = 4 GeV (upper) and m(d') = 5 GeV (lower). (Fro R. M. Barnett).

is a reproduction from Barnett's work, which does give a satisfactory account of the HPWF $<y>^{\nu}$ data for $m_b \approx 5$ GeV. We recall that this parametrization gives the best fit to the CITF data as Barish noted.

The high y anomaly and the increase in $\sigma_{\bar{\nu}}/\sigma_{\nu}$ are important issues which may point to the existence of new quarks beyond the charmed one. I do not think all the issues are completely settled either experimentally or theoretically. More work needs to be done.

J. Parity-violating effects in atomic physics are about to be confirmed. Let me briefly summarize the status of one experiment, done at the University of Washington. It deals with the dispersive optical rotation of a laser beam transmitted through Bi vapor. The transition from the ground state $(6p)^3\left[{}^4S_{3/2}\right]$ to the first excited state $(6p)^3\left[{}^2D_{3/2}\right]$ is M1 in the absence of a parity admixing. For a reasonable choice of the weak angle $\theta_W \approx 35^\circ$, the theoretical expectation based on the minimal model is $+3.4 \times 10^{-7}$ rotations/absorption length. I understand that the group at Washington observes an effect of the right sign and of the same magnitude. I understand further than the background due to the geomagnetic Faraday effect is under control.

K. Weak π^0 production: T. Hansl (Aachen-Padova) and W. Lee (Columbia-Illinois-Rockefeller) reported on weak π^0 production experiments carried out at CERN and BNL, respectively. The quantities of interest are

$$R_0 = \frac{\sigma(\nu + p \rightarrow \nu + p + \pi^0) + \sigma(\nu + n \rightarrow \nu + n + \pi^0)}{2\sigma(\nu + n \rightarrow \mu^- + p + \pi^0)}$$

for which the theoretical expectation based on the minimal model (S. Adler) is, with $x_W = \sin^2 \theta_W$:

x_W	R_0: $\Delta(1236)$ + nonresonant background
0.3	0.40
0.4	0.33

and

$$R_o' = \frac{\sigma(\nu + T \to \nu + T' + \pi^o)}{\sigma(\nu + T \to \mu^- + T'' + \pi^o}\ ,\quad \bar{R}_o' = \frac{\sigma(\bar{\nu} + T \to \bar{\nu} + T' + \pi^o)}{\sigma(\bar{\nu} + T \to \mu^+ + T''' + \pi^o}$$

where T denotes a nuclear target (in both cases it is mostly Al). R_o' is significantly different from R_o due to the charge exchange effect within the target nucleus. The theoretical expectation worked out by Adler, Nussinov and Paschos is

x_W	R_o'	$\bar{R}_o'$
0.3	0.23	
0.35	0.2	0.25
0.4	0.18	

The experimental values are

$$R_o' = 0.17 \pm 0.04$$

(Columbia-Illinois-Rockefeller)

$$\bar{R}_o' = 0.39 \pm 0.18$$

and

$$R_o'/\bar{R}_o' = 0.66 \pm 0.15 \text{ (Aachen-Padova)} \ .$$

The Aachen-Padova group makes a fiducial cut $E_{\pi^o} \gtrsim 300$ MeV, so that the separate values of R_o' and $\bar{R}_o'$ are not to be compared with the theoretical expectation. I understand that the ratio $R_o'/\bar{R}_o'$ is relatively insensitive to this restriction.

It is to the credit of these groups to explore the nature of neutral currents, parasitically behind bubble chambers, and with uncomplicated detectors by today's standard. More interesting questions, such as the evidence for N^* production by neutral current, and the isospin structure of neutral current, can be studied through weak pion production, and future research should be channeled into these fertile fields.

L. Purely leptonic processes: At this Conference a number of new results on purely leptonic weak processes were reported. We shall parametrize

$$\begin{bmatrix} \sigma(\bar{\nu}_e e \to e^- \bar{\nu}_e) \\ \sigma(\nu_\mu e^- \to e^- \nu_\mu) \\ \sigma(\bar{\nu}_\mu e^- \to e^- \bar{\nu}_\mu) \end{bmatrix} = \begin{bmatrix} C_{\bar{\nu}_e e} \\ C_{\nu_\mu e} \\ C_{\bar{\nu}_\mu e} \end{bmatrix} \times (E/\mathrm{GeV}) \times 10^{-41}\ \mathrm{cm}^2 .$$

We will list theoretical expectations for the coefficients:

	Minimal gauge theory	V-A theory
$C_{\bar{\nu}_e e}$	$0.14 \sim 2.9\ (0 < x_W < 1)$	0.57
$C_{\nu_\mu e}$	0.11 at x_W 0.35	0
$C_{\bar{\nu}_\mu e}$	0.22 at x_W 0.35	0

New experimental values, together with previous ones are listed below:

	New	Old
$C_{\bar{\nu}_e e}/0.57$	0.87 ± 0.25 ($1.5 \sim 3$ GeV) 1.70 ± 0.44 ($3 \sim 4$ GeV) observed; F. Reines et al. (UCI)	1.5 ± 0.7 upper limit with 2σ; Rein et al. (UCI)
$C_{\nu_\mu e}$	0.24 ± 0.12 (Aachen-Padova)	< 0.26 (no event; Gargamelle)
$C_{\bar{\nu}_\mu e}$	$0.11\ {}^{+0.21}_{-0.09}$ (Gargamelle) 0.54 ± 0.17 (Aachen-Padova)	0.13 ± 0.08 (3 events; Gargamelle; efficiency connection made with th minimal model)

M. Elastic νp, and $\bar{\nu} p$ scattering: W. Lee of the Columbia-Illinois-Rockefeller group reported on elastic νp scattering observed at BNL, and Larry Sulak of the Harvard-Pennsylvania-Wisconsin group reported on elastic νp and $\bar{\nu} p$ scattering observed also at BNL.

For νp scattering, the results are

$$R_{el}^{\nu} \equiv \sigma(\nu p \to \nu p)/\sigma(\nu n \to \mu^- p) = 0.23 \pm 0.09 \quad \text{(CIR)}$$

$$= 0.17 \pm 0.05 \quad \text{(HPW)} \quad .$$

Fiducial cuts used by the two groups are somewhat different: for the CIR experiment the recoil proton momentum is required to be ≥ 550 MeV, the recoil angle, $\geq 25^{o}$; for the HPW experiment, it is required that $0.3 \leq q^2 \leq 0.9\ (\text{GeV})^2$. The two results are in agreement to within the quoted errors.

For $\bar{\nu}p$ scattering the HPW experiment yields

$$R_{el}^{\bar{\nu}} = \sigma(\bar{\nu}p \to \bar{\nu}p)/\sigma(\bar{\nu}p \to \mu^+ n) = 0.2 \pm 0.1 \quad \text{(HPW)}$$

with the fiducial cut as above.

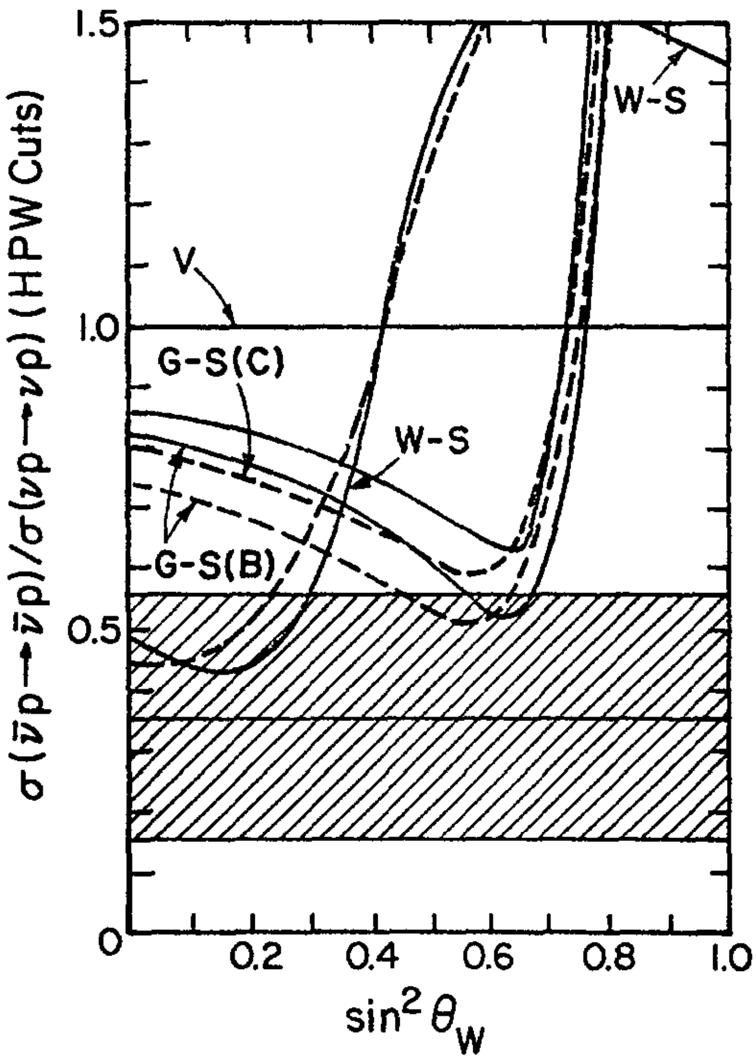


Fig. 11. The ratio of flux averaged antineutrino to neutrino cross sections, $\sigma(\bar{\nu}p \to \bar{\nu}p)/\sigma(\nu p \to \nu p)$, for the HPW cuts, as a function of $\sin^2\theta_W$. The curves are for the Weinberg-Salam (W-S), vector (V), and Gürsey-Sikivie (G-S) (B) and (C) models. The solid and dashed curve correspond to an axial vector form factor with $M_A{}^2 = 0.71\ \mathrm{GeV}^2$ and $1.32\ \mathrm{GeV}^2$, respectively. The HPW result, $\sigma(\bar{\nu}p \to \bar{\nu}p)/\sigma(\nu p \to \nu p) = 0.35 \pm 0.2$, is represented by the shaded band with central line. (from Albright, Quigg, Shrock, and Smith; hereafter AQSS)

In Figure 11, the ratio $\sigma(\bar{\nu}p \to \bar{\nu}p)/\sigma(\nu p \to \nu p)$ of the HPW group is compared with the expectations based on various models. The vector model (V) is clearly ruled out; the minimal model (W-S) is consistent with the data for $x_W \approx 0.3$. $\left[\text{The official HPW value is } x_W = 0.3\ {}^{+0.05}_{-0.1}\right]$. This and the following two figures are from the work of C. Albright, C. Quigg, R. Shrock and J. Smith[8]. In Figures 12 and 13,

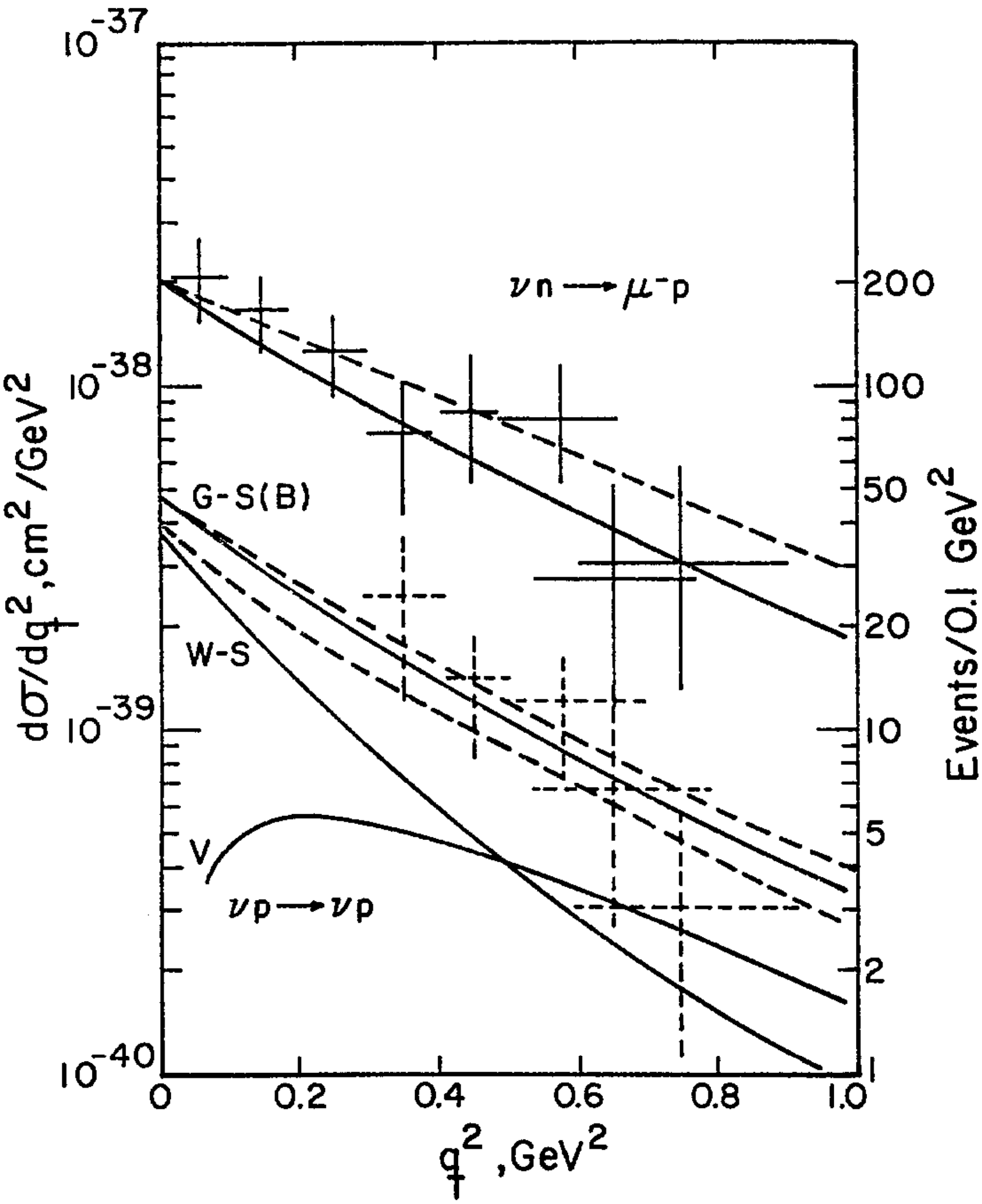


Fig. 12. Differential cros sections for elastic νp scattering and for quasi-elastic neutrino scattering in the Weinberg-Salam model with $\sin^2\theta_W = 0.4$. Solid curves correspond tc an axial form factor with $M_A{}^2 = 0.71$ GeV^2; the dashed curves are for $M_A{}^2 = 1.32$ GeV^2. Data are from the HPW experiment. (from AQSS)

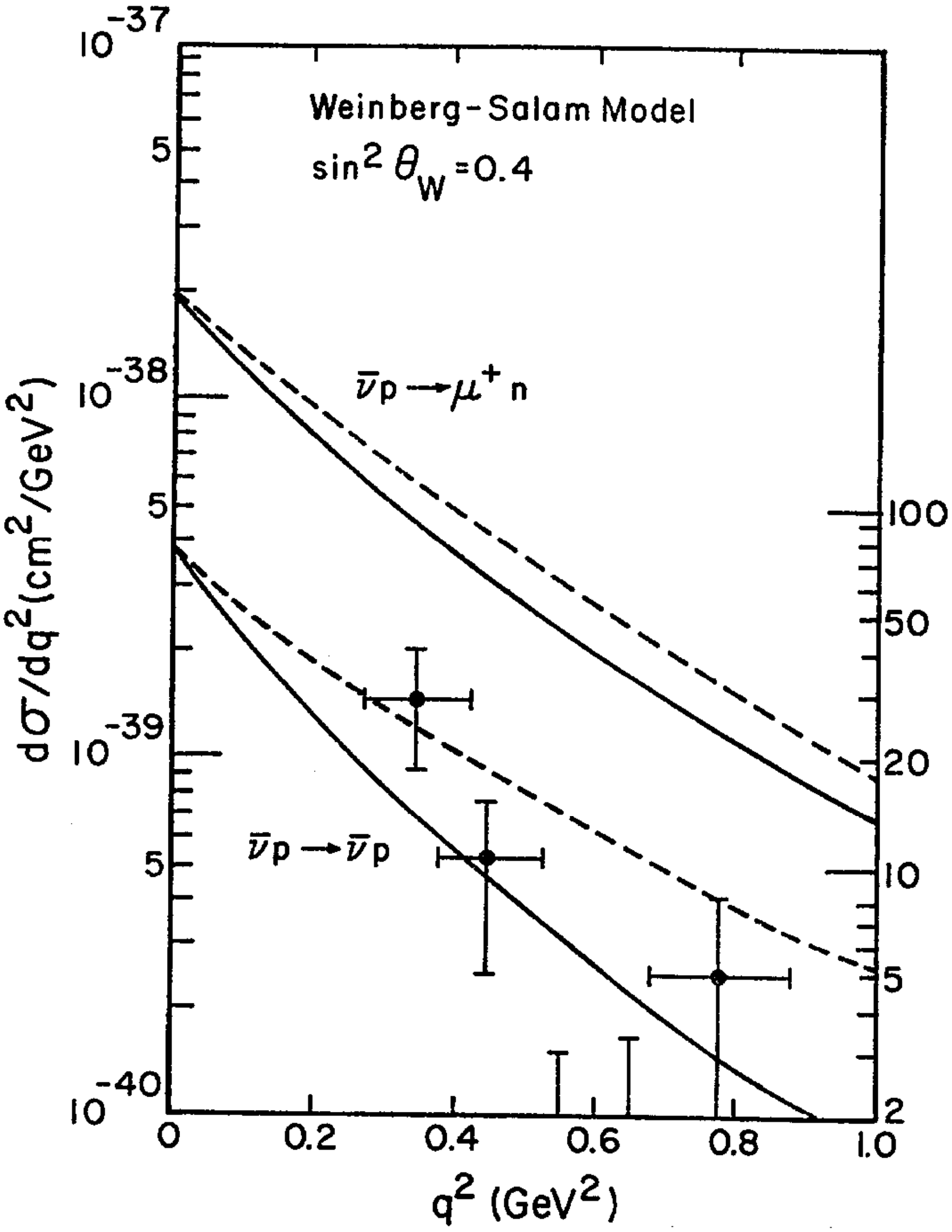


Fig. 13. Differential cros sections for elastic $\bar{\nu}p$ scattering and for quasi-elastic antineutrino scattering in the Weinberg Salam model with $\sin^2\theta_W$ 0.4. Solid curves correspond to an axial for factor with $M_A^2 = 0.71$ GeV^2; the dashed curves a for $M_A^2 = 1.32$ GeV^2. Da are from the HPW experiment. (from AQSS)

the q^2 distributions for νp and $\bar{\nu}p$ scattering of the HPW group are compared with the predictions of the minimal model. Again, the vector model seems to be ruled out, and the minimal model appears in reasonable agreement with data.

N. Inclusive neutral current measurements: At last, there is a reasonable convergence of the values R^{ν} and $R^{\bar{\nu}}$:

$$R^{\nu} = \sigma(\nu + N \to \nu + X')/\sigma(\nu + N \to \mu^{-} + X)$$

and similarly for $R^{\bar{\nu}}$, of various groups, as shown in the table below:

Experiment	R^{ν}	$R^{\bar{\nu}}$	Remarks
Gargamelle (W. von Donink)	0.28 ± 0.04	0.39 ± 0.06	$\langle E\rangle \sim 2$ GeV, $E_h \geq 1$ GeV
HPWF (T.-Y. Ling)	0.29 ± 0.04	0.39 ± 0.10	$\langle E_{\nu}\rangle = 53$ GeV, $\langle E_{\bar{\nu}}\rangle \sim 41$ GeV, $E_h \geq 4$ GeV
CITF	0.24 ± 0.04	0.35 ± 0.11	$\langle E\rangle \sim 50$ GeV, $E_h \geq 12$ GeV

The y-dependence has also been studied by the above three groups. All groups use the parametrization:

$$d\sigma_{\nu}^{NC}/dy = \frac{G_F^2 m_N E_{\nu}}{\pi}\left[A_L + A_R(1-y)^2\right]$$

$$d\sigma_{\bar{\nu}}^{NC}/dy = \frac{G_F^2 m_N E_{\nu}}{\pi}\left[A_R + A_L(1-y)^2\right] .$$

The values for A_L/A_R reported at this Conference are

Experiment	A_L/A_R
Gargamelle	$(0.11 \pm 0.02)/(0.036 \pm 0.011)$
HPWF	$0.9/0.1$
CITF	$(.20 \pm 0.2)/(.11 \pm 0.4)$.

All that can be said about this is that all groups agree that the hadronic neutral current is parity violating.

O. Consensus on the value of $x_W = \sin^2\theta_W$: I have made a plot of ranges of $\sin^2\theta_W$ reported at this Conference, as shown in Figure 14.

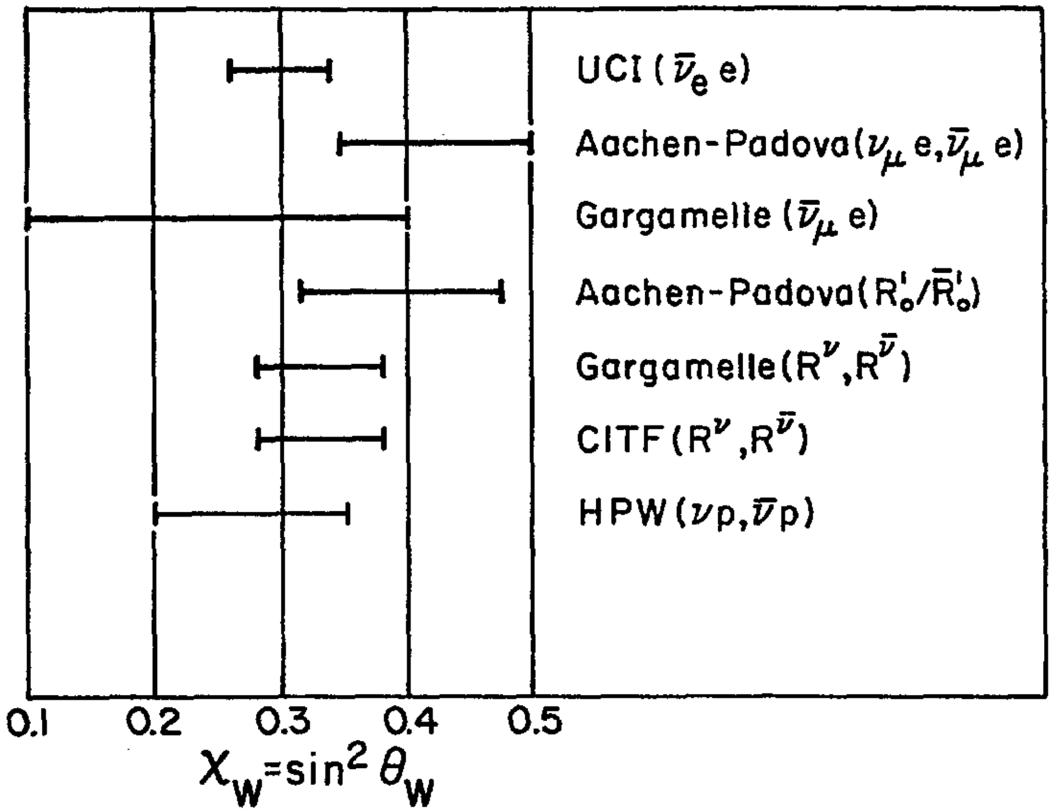


Fig. 14. Range of $x_W = \sin^2\theta_W$ reported at the Conference.

Instead of presenting you with the best value for x_W by the χ^2 test, I would suggest a value which at least serves as easy mnemonic,

$$\sin^2 \theta_W = \frac{1}{3} .$$

III. SUNDRY IDEAS

A. There are still a few "table-top" neutrino experiments one can perform. One of them is the detection of the process $K_L \to \nu\bar{\nu}$. If nothing else, it is a supreme test of human ingenuity. Another is the decay of ψ into $\nu\bar{\nu}$, through the chain[9]

$$\begin{array}{l} \psi' \to \psi + \pi^+ + \pi^- \\ \quad\;\; \hookrightarrow \nu + \bar{\nu} \, . \end{array}$$

B. Neutrino oscillation: This has been discussed by Pontecorvo and Gribov[10], Eliezer, Ross and Swift[11], Fritzsch and Minkowski[12]. I understand that Al Mann and Henry Primakoff[13] are examining this process for feasibility of a terrestrial experiment.

Let me motivate the idea in the context of the minimal gauge theory. If we pursue lepton-hadron symmetry to its ultimate, we may postulate that the two lepton doublets are

$$\begin{pmatrix} \nu_e \cos\theta - \nu_\mu \sin\theta \\ e \end{pmatrix}_L , \begin{pmatrix} \nu_\mu \cos\theta + \nu_e \sin\theta \\ \mu \end{pmatrix}_R$$

where ν_e and ν_μ are Dirac four-component spinors of definite mass, and θ is a Cabibbo-like angle for leptons. I shall not review here the limits on m_e and m_μ which follow from terrestial experiments or from astrophysical considerations (For these, see Efremenko's and Marx' contributions in these Proceedings).

If this postulate is correct, then the probability that a neutrino produced in association with a μ^+ at t = 0 (z = 0) will produce an electron at a target at z $\simeq$ ct is given by

$$P(e^-, t|\mu^+, 0) \simeq 2\cos^2\theta \sin^2\theta\left(1 - \cos\frac{\Delta m^2}{2p} t\right)$$

where $\Delta m^2 = |m^2(\nu_\mu) - m^2(\nu_e)|$, and p is the momentum carried by the neutrino. For the moment, I do not know of any reason why $\sin\theta$ could not be as large as $1/\sqrt{2}$. On the other hand, it is perhaps more probable that $\theta \approx \theta_C$.

As Eliezer and Ross[11] pointed out some time ago, this scheme allows the process $\mu \to e + \gamma$, albeit GIM-suppressed. The branching ratio for this decay is given by

$$B.R.(\mu \to e\gamma) \sim \cos^2\theta \sin^2\theta\left(\frac{\Delta m^2}{m_\mu^2}\right)^2$$

which is, experimentally, a few times 10^{-8}. Assuming $\theta = \theta_C$, they deduce the bound

$$|\Delta m^2| \lesssim (1\ \mathrm{eV})^2.$$

If this is correct, the oscillation length defined as

$$\ell_{osc} = \frac{4\pi p}{\Delta m^2}$$

is of order 10 km for p = 20 GeV.

The Mann-Primakoff proposal consists of shooting the neutrino beam 76 mr below horizon, and placing a detector about 1000 km away, somewhere in Québec.

IV. EPILOGUE

In 777, Charlemagne began the construction of the capital of his Empire stretching from Denmark to the Adriatic here at Aix-la-Chapelle, partly because he enjoyed to swim and relax in a hot spring nearby. He intended that Aix-la-Chapelle be not only the center of administration, but also a citadel of learning and knowledge, in order to revive, or at least to preserve, what we know today as Western Civilization. As Kenneth Clark aptly reminds us, only three or four antique manuscripts of the Latin authors are still in existence: practically all knowledge of Latin scholarship is preserved for us through transcriptions done at his time at Aix-la-Chapelle and elsewhere in the beautiful Carolingian script.

It is fitting that, almost exactly twelve centuries later, we gather here to celebrate one of the crowning achievements of this century, which

I shall call "neutrino microscopy". We see quarks rattling about inside a hadron by bouncing neutrinos off them. In a sense, the Neutrino Area at Fermilab, and the West Hall of SPS are gigantic microscopes of unprecedented proportions. It is not as important that we do not fully comprehend, and do not always agree on, what we see; it is very important that our vistas are constantly expanding by this endeavor.

For this pleasure, we owe our gratitude to Professor Helmut Faissner and his colleagues, and I wish to express, on behalf of the particpants, appreciation of their efforts and hospitality. Thank you.

Thanks are due to Robert E. Shrock for his help in the preparation of this manuscript.

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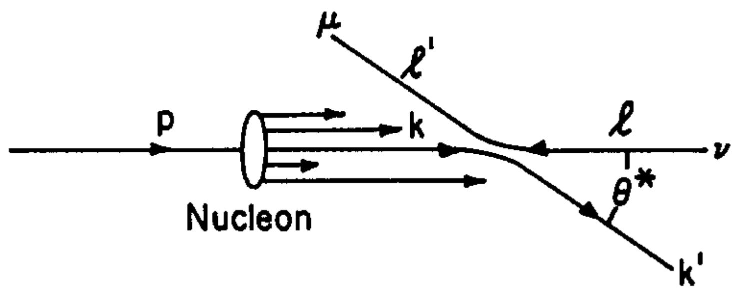
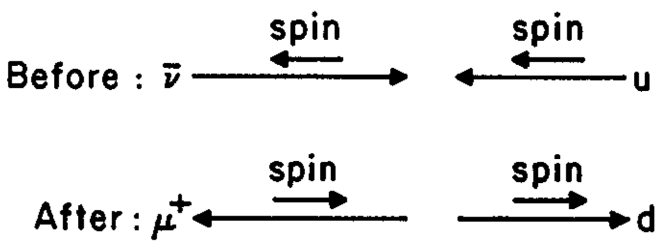
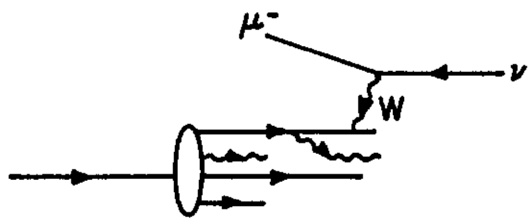
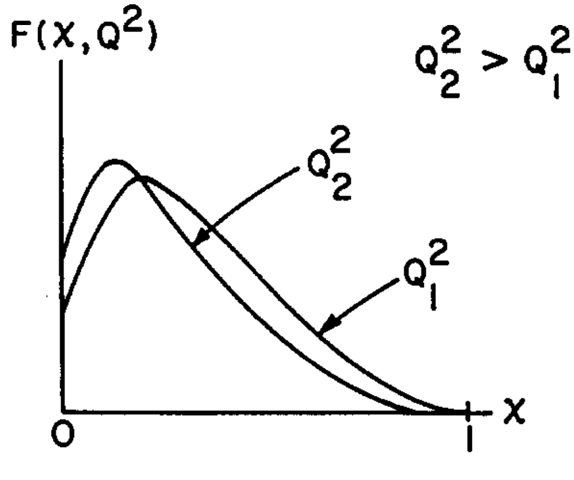


μ
ℓ'
p
k
ℓ
ν
θ*
Nucleon
k'

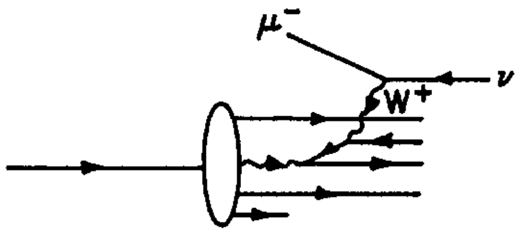

spin
spin
Before : $\bar{\nu}$
u
spin
spin
After : μ^+
d



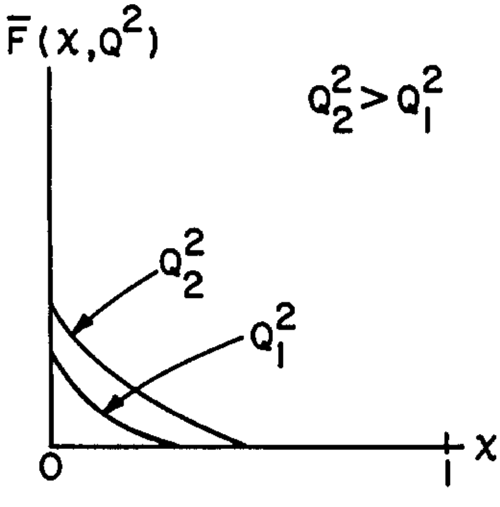
μ⁻
ν
W



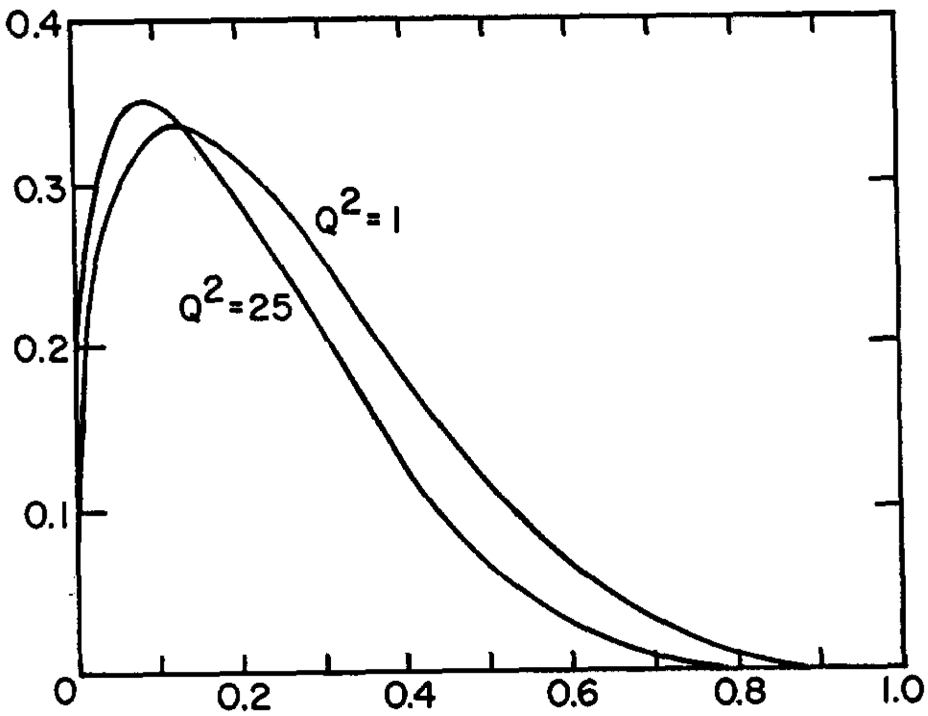
F(X, Q²)
Q²₂ > Q²₁
Q²₂
Q²₁
X
O
I



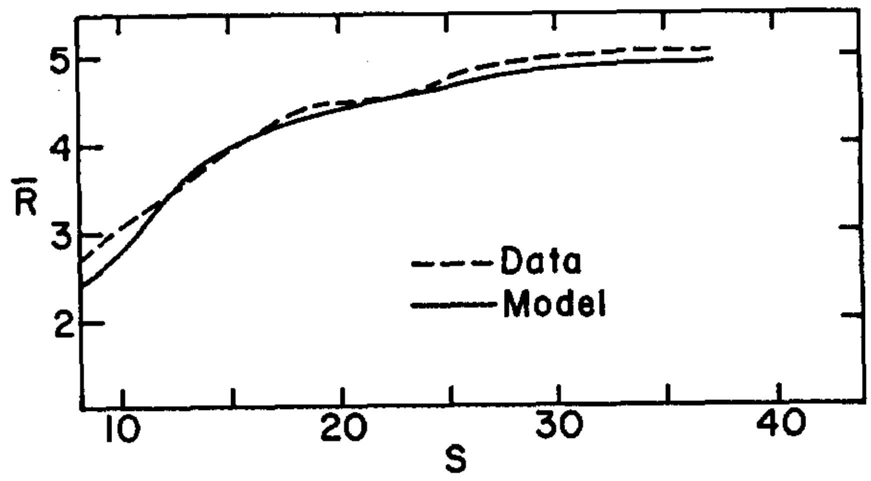
μ⁻
W⁺
ν



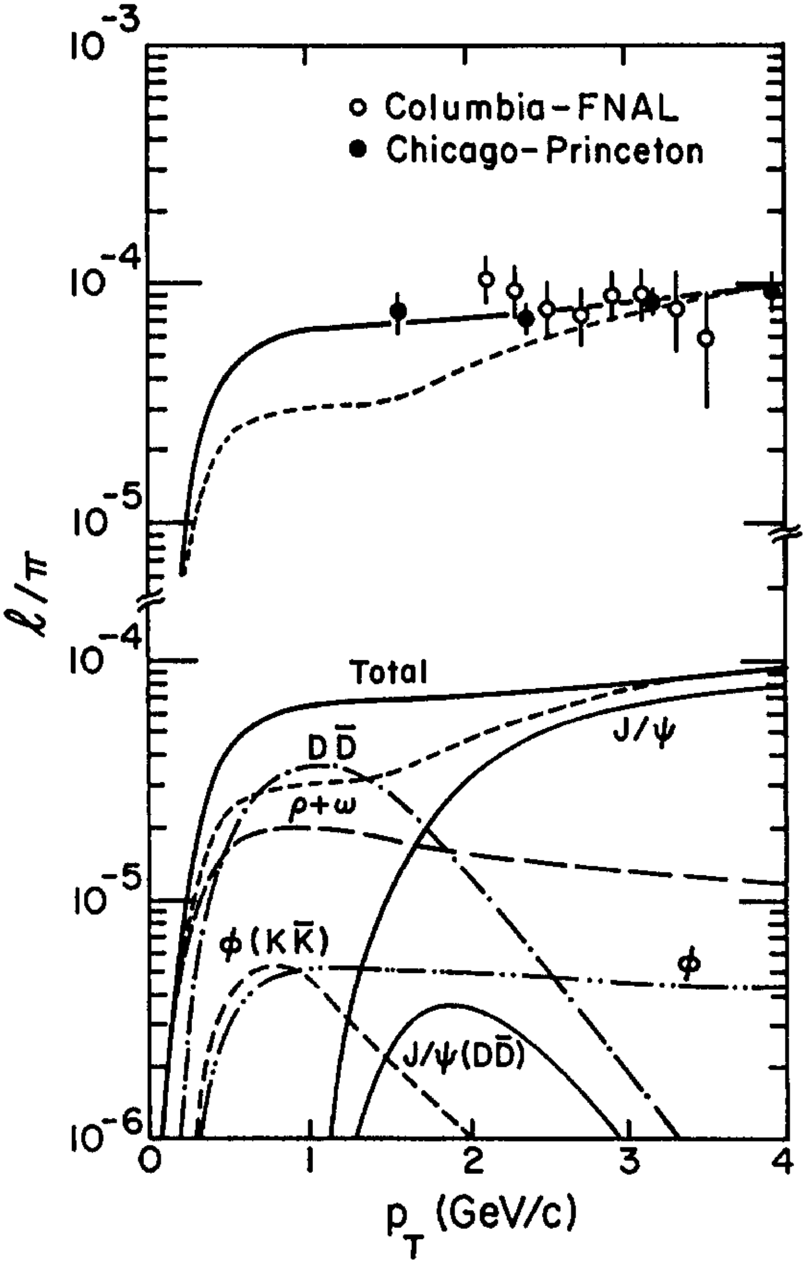
$\bar{F}(x,Q^2)$
$Q_2^2 > Q_1^2$
Q_2^2
Q_1^2
0
1
x



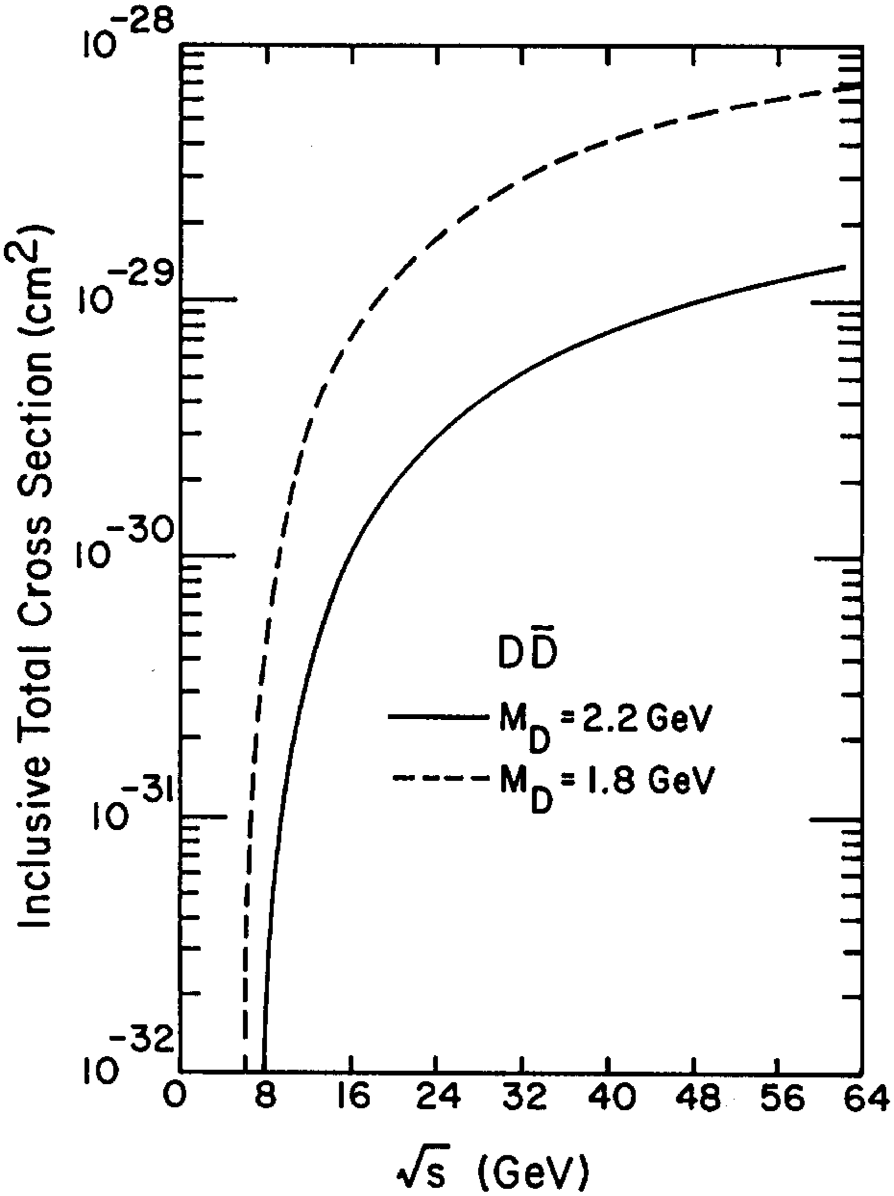
0.4
0.3
0.2
0.1
0
0.2
0.4
0.6
0.8
1.0
$Q^2=1$
$Q^2=25$



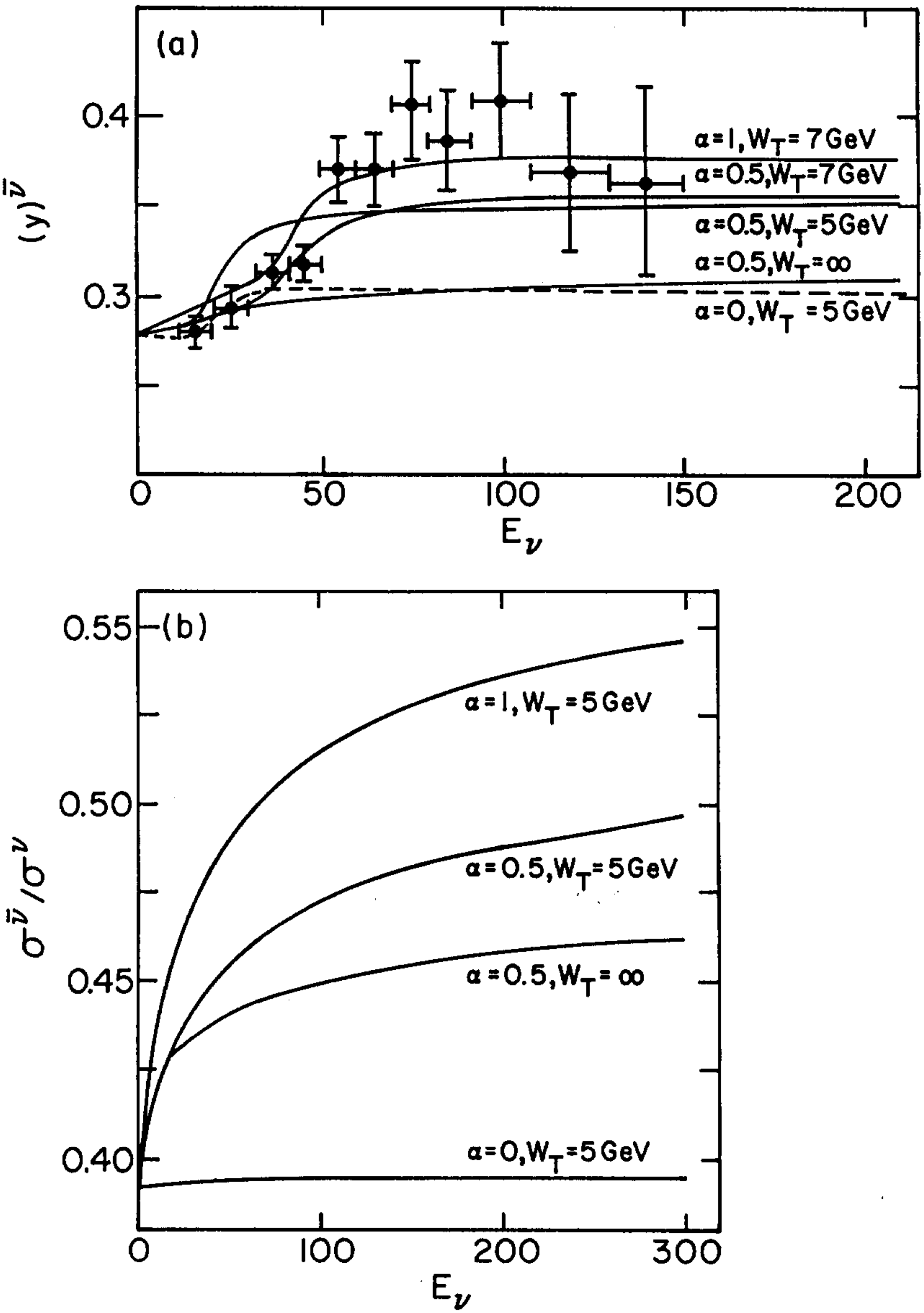
5
4
3
2
$\bar{R}$
Data
Model
10
20
30
40
S



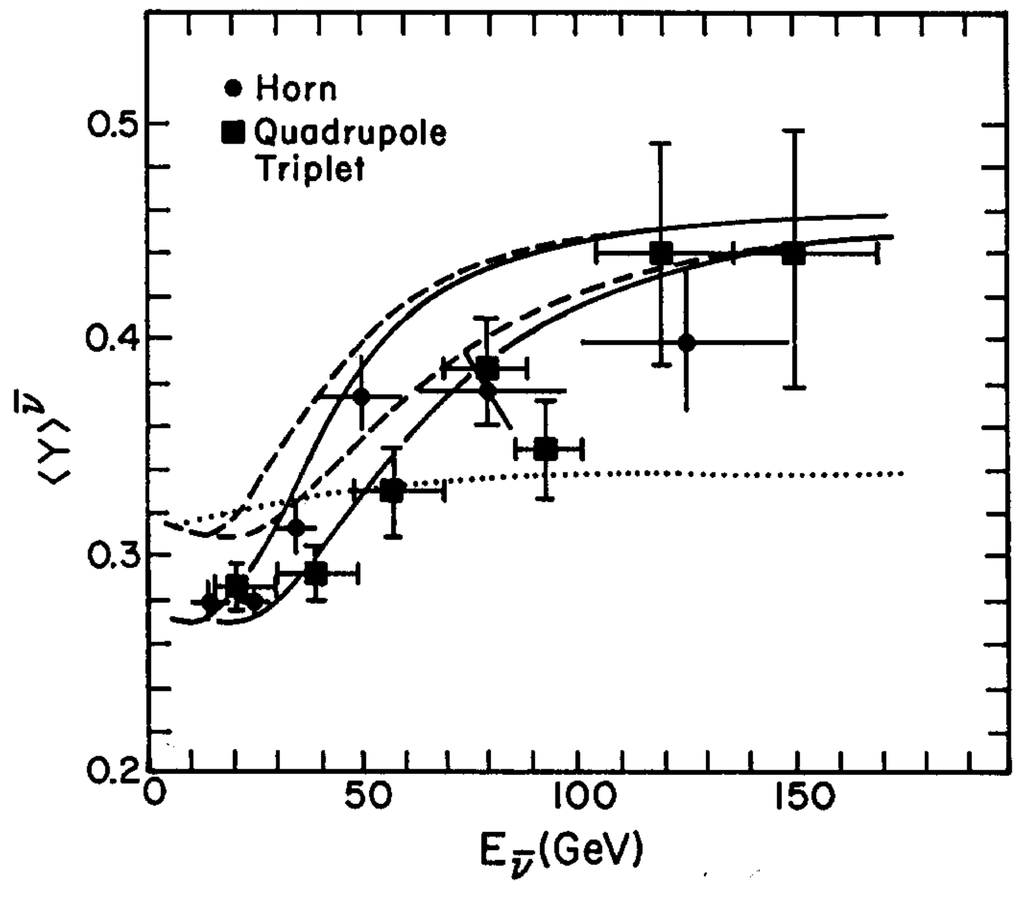
Columbia-FNAL
Chicago-Princeton
Total
DD̄
ρ+ω
J/ψ
φ(KK̄)
φ
J/ψ(DD̄)
ℓ/π
p_T (GeV/c)



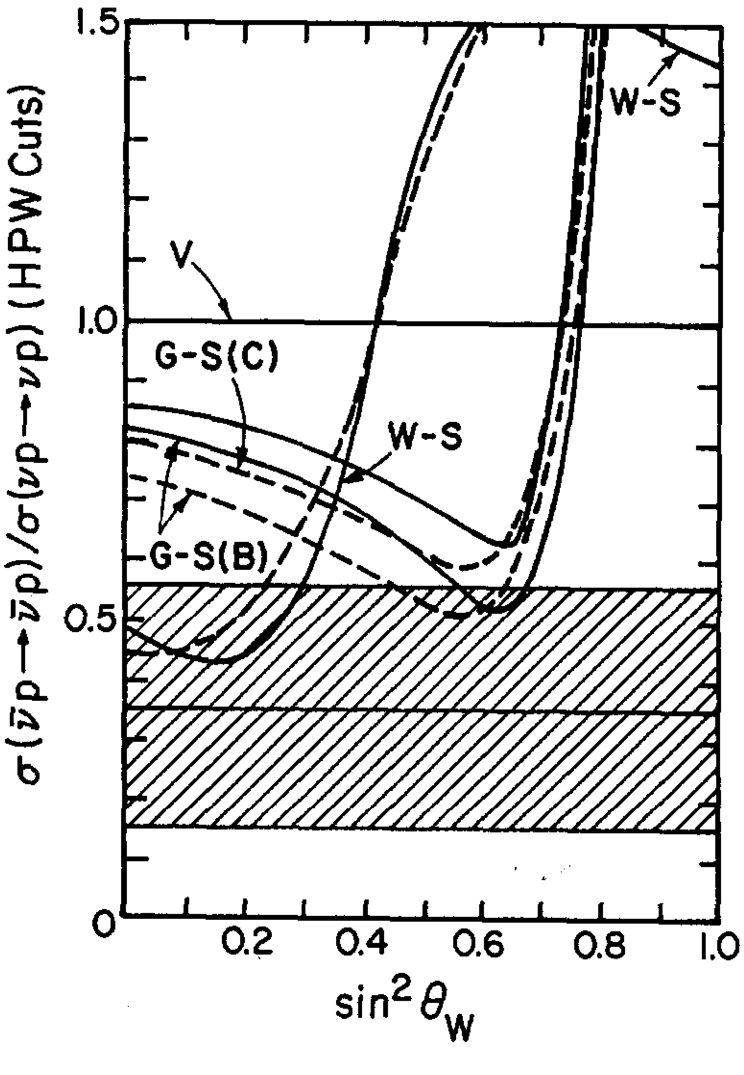
Inclusive Total Cross Section (cm2)
10-28
10-29
10-30
10-31
10-32
0
8
16
24
32
40
48
56
64
√s (GeV)
DD̄
MD = 2.2 GeV
MD = 1.8 GeV



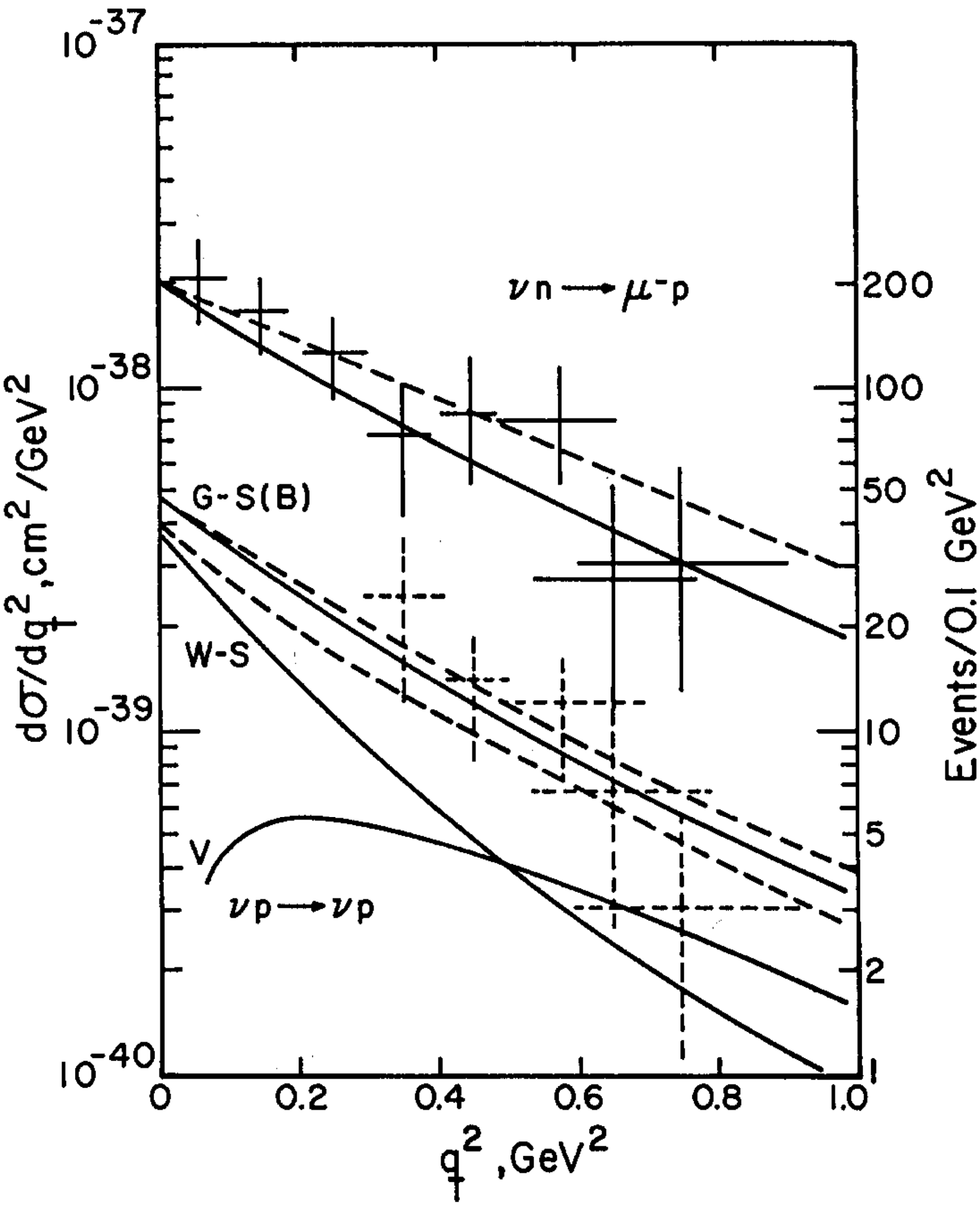
(a)
0.4
0.3
$(y)^{\bar{\nu}}$
α=1, W_T= 7GeV
α=0.5, W_T=7GeV
α=0.5, W_T=5GeV
α=0.5, W_T=∞
α=0, W_T = 5GeV
0
50
100
150
200
E_ν
(b)
0.55
0.50
0.45
0.40
$\sigma^{\bar{\nu}}/\sigma^{\nu}$
α=1, W_T=5GeV
α=0.5, W_T=5GeV
α=0.5, W_T=∞
α=0, W_T=5GeV
0
100
200
300
E_ν



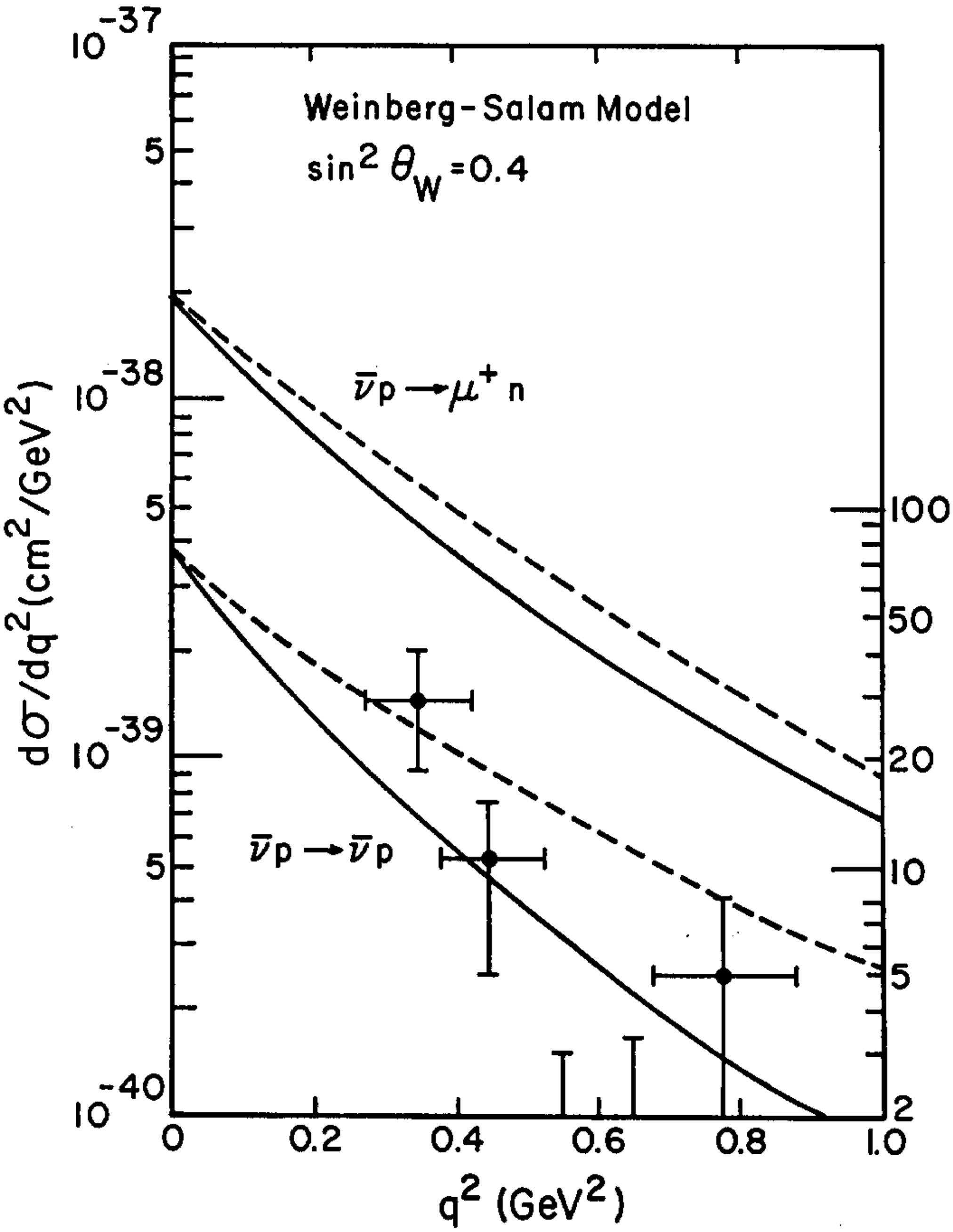
Horn
Quadrupole
Triplet
0.5
0.4
0.3
0.2
0
50
100
150
⟨Y⟩$^{\bar{\nu}}$
$E_{\bar{\nu}}$(GeV)



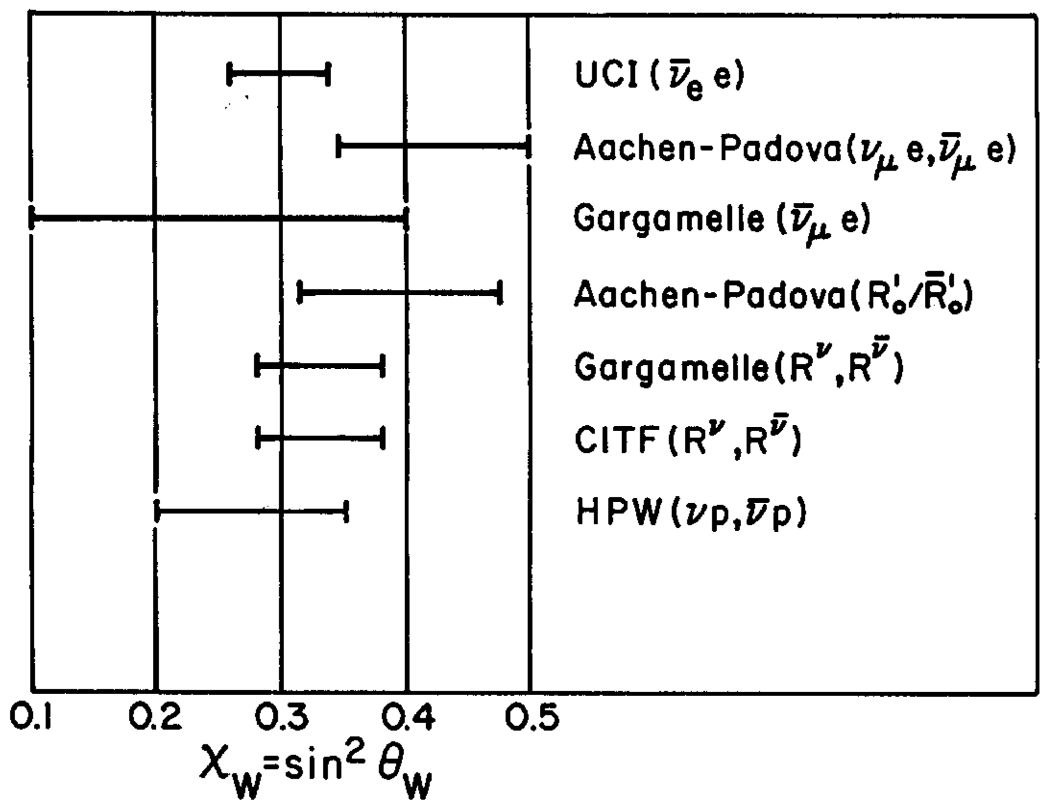
$\sigma(\bar{\nu}p \rightarrow \bar{\nu}p)/\sigma(\nu p \rightarrow \nu p)$ (HPW Cuts)
$\sin^2\theta_W$
1.5
1.0
0.5
0
0.2
0.4
0.6
0.8
1.0
V
G-S(C)
W-S
G-S(B)
W-S



10^{-37}
10^{-38}
10^{-39}
10^{-40}
$d\sigma/dq^2$, cm^2/GeV^2
$\nu n \longrightarrow \mu^- p$
G-S(B)
W-S
V
$\nu p \longrightarrow \nu p$
0
0.2
0.4
0.6
0.8
1.0
q^2, GeV^2
200
100
50
20
10
5
2
1
Events/0.1 GeV^2



Weinberg-Salam Model
$\sin^2\theta_W = 0.4$
$\bar{\nu}p \rightarrow \mu^+ n$
$\bar{\nu}p \rightarrow \bar{\nu}p$
$d\sigma/dq^2 (cm^2/GeV^2)$
q^2 (GeV^2)
10^{-37}
5
10^{-38}
5
10^{-39}
5
10^{-40}
0
0.2
0.4
0.6
0.8
1.0
100
50
20
10
5
2



UCI ($\bar{\nu}_e e$)
Aachen-Padova($\nu_\mu e, \bar{\nu}_\mu e$)
Gargamelle ($\bar{\nu}_\mu e$)
Aachen-Padova($R'_o/\bar{R}'_o$)
Gargamelle($R^\nu, R^{\bar{\nu}}$)
CITF ($R^\nu, R^{\bar{\nu}}$)
HPW ($\nu p, \bar{\nu} p$)
0.1
0.2
0.3
0.4
0.5
$x_W = \sin^2 \theta_W$